HEMISPHERIC SPECIALIZATION FOR HANDWRITING

By

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For

My father,
Oliver Mack Sr.,
who
believed in me
and
applauded loudest
in his heart.

Oliver Mack Sr.
September 21, 1931
November 7, 1986

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It has been previously demonstrated in right-handers that while distal limb movements are controlled by the contralateral (left) hemisphere, more proximal limb movements may be controlled by the ipsilateral (right) as well as contralateral hemisphere. It has also been shown that the left hemisphere is programmed for both linguisitic and motor skills. In order to learn whether language dominance, bilateral motor dexterity or lateralized skilled praxis engrams determine distal hand superiority of preferred hand movements over nonpreferred hand movements, right-handed and left-handed subjects were studied with writing, drawing and tracing tasks. Moreover, in order to assess the influence of handwriting posture on hand movements, Right-Handed Noninverters, Left-Handed Inverters and Left-Handed Noninverters were participants in the study.

Results of statistical and descriptive analysis of data revealed that Right-Handed Noninverters used distal movements when using their right hand and proximal movements when using their left hand. Left-Handed Inverters showed the opposite pattern; they used distal movements while performing the tasks with their left hand and proximal movements while performing the same tasks with their right hand. On the other hand, Left-Handed Noninverters showed no significant differences in their distal versus proximal hand movements while performing the first two experimental tasks and inconsistent patterns of hand performance on the third experimental task.

The best fitting model to explain the hand movements observed in the right-handed individuals is the motor skill superiority model. As predicted, Right-Handed Noninverters used distal movements with their right hand and proximal movements with their left hand. Conversely, Left-Handed Inverters consistently used distal left hand movements and proximal right hand movements while performing the writing, drawing, and tracing tasks. On the basis of those findings, it is again concluded that the dexterity model fits as the best explanation for the observed hand movements of Left-Handed Inverters. Since the differences detected between the Left-Handed Noninverters' right hand and left hand tracing performance did not reach a level of significance it appears that the findings can not be explained in terms of

this study demonstrate a simple neuropsychological technique that may be used to study hemispheric specialization.

CHAPTER 1

INTRODUCTION

Writing is a very complex function combining linguistic, kinaesthetic, visual, acoustic, praxic, and motor components. The linguistic component includes the choice of the correct words and letters. The kinaesthetic and visual systems are mainly important for feedback and the acoustic part is primarily important in dictation. The praxis system contains a spatial temporal code (movement formula) that programs the motor system so that the hand and arm make well formed letters.

The motor system including upper motor neurons and motor units bring these motor formulae into function by sequentially activating the appropriate muscles. Upon activation of the appropriate muscles, muscle contraction occurs and movement is accomplished. The control of writing movement requires multiple inputs to the central nervous system from both peripheral and central sources (Medical Neuroscience Manual (Vol. II), Department of Neuroscience, College of Medicine, University of Florida, 1986).

Damage to the central nervous system may result in a disorder of writing called agraphia. The diagnosis of

acquired agraphia implies total or partial inability to write as the result of neurological dysfunction (Benson, 1979). However, not all cases of agraphia are the same. Agraphia may reflect either motoric deficits resulting in poor grapheme formation, or may reflect linguistic deficits as evidenced by specific patterns of disability of grapheme choice or word choice. I will hereafter refer to these as executive agraphias and linguistic agraphias, respectively.

Margolin (1984) described three routes of spelling (see the linguistic portion of Figure 1.1) including a nonlexical-phonological route, a lexical phonological route, and a semantic route. Normal spellers spell words (either orally or in written form) via automatic activation of all three routes simultaneously and in parallel.

The nonlexical-phonological route (also referred to as "phonologic") allows one to spell unfamiliar words (e.g., "mawusi") and nonsense words (e.g., "blek") by means of "phoneme-to-grapheme" conversion rules (Coltheart, 1978). When spelling familiar words, the skilled speller preferentially uses the lexical phonological (also referred to as "visual," "lexical," or "whole word") route, which allows the speller to access the corpus of sounds in his mental lexicon (Rothi, Roeltgen, & Kooistra, 1987). The semantic spelling route is described as a direct association between one's abstract store of word meanings and the word's orthography (Margolin, 1984).

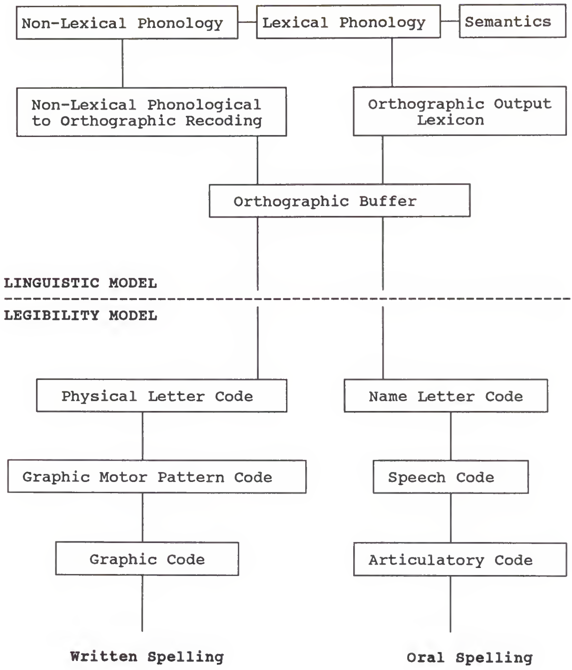


Figure 1.1. Overall Model of Handwriting Control. (Margolin, 1984)

Just as it is necessary that semantics interact with orthography (a part of language that deals with letters and spelling to produce correct spelling), it is necessary that a physical letter code interact with graphic output skills to facilitate legible writing (see the legibility portion of Figure 1.1). While the orthographic buffer specifies the letter necessary to spell a particular word and maintains the proper letter order, the physical letter code must specify acceptable forms (physical) of the letter specified by the orthographic buffer. Failure of this interactive process may result in an unacceptable physical version of the specified letter (e.g., upper case vs. lower case letters). Beyond the orthographic buffer, the graphic motor pattern code (Ellis, 1982) is also necessary. This code specifies the sequence of strokes necessary to complete the form dictated by the physical letter code. The final stage in handwriting, the graphic code, translates the information from the graphic pattern into specific neuromuscular instructions (muscle innervation, force, and speed of writing).

Research on acquired agraphia has provided evidence to document at least nine types of agraphias; four executive agraphias and five lingusitic agraphias. I will discuss the linguistic agraphias first and the executive agraphias subsequently.

Linguistic Agraphias

An inability to access the nonlexical-phonological spelling route has been described as either the syndrome of phonological agraphia (Shallice, 1981; Roeltgen, Sevush, & Heilman, 1983) or phonological agraphia with associated findings; deep agraphia (Bub & Kertesz, 1982; Hatfield, 1982). Both syndromes are characterized by impaired ability to spell nonwords in the context of preserved ability to spell both words with direct sound-to-letter correspondence rules and words that cannot be spelled utilizing direct sound-to-letter corespondence rules, hereafter referred to as regular words and irregular real words, respectively. However, these syndromes are distinguishable not only in the differences in brain mechanisms proposed as responsible for them but also in the behavioral characteristics of the resulting writing disorders. The phonological agraphic patient is able to spell words with a high degree of visual resemblance to the target word (e.g., "little" for "litter"). In contrast, the hallmark of deep agraphia is the semantic paragraphias that these patients make in addition to their inability to spell nonwords. That is, they may spell a real word that is related in content to the target word, but not phonologically or visually similar to the target. For example, they might spell "window" for "door." Additionally, patients with deep agraphia have trouble spelling function words and nouns of low

imageability (Roeltgen, Sevush, & Heilman, 1983). Therefore they have particular spelling difficulties with pronouns, prepositions, adverbs, conjunctions, and abstract words such as "mind," "love," "think," etc. Also the lesion site common to phonological agraphia has been credited to lesions of the supramarginal gyrus or the insula medial to it (or both) while reported cases of deep agraphia have had large lesions of the supramarginal gyrus or insula extending well beyond the circumscribed area thought to be important for phonological agraphia. (Roeltgen et al., 1983).

Dysfunction of the lexical phonological system is called lexical agraphia, (Beauvois & Derouesne, 1981; Roeltgen & Heilman, 1983; Hatfield & Patterson, 1983) a spelling disorder characterized by an impaired ability to spell irregular and words with ambiguous spellings (words with sounds that may be represented by multiple letters or letter clusters, e.g., "photo") hereafter referred to as ambigously spelled words with preserved ability to spell regular words and nonsense words. These patients have difficulty spelling irregular words, for which there is no direct phoneme-to-grapheme correspondence (e.g., "island"). The resulting paragraphic errors of the lexical agraphic may be phonologically similar to the target word (e.g., "Wednesday" results in "Wenzday"). The junction of the posterior angular gyrus and the parieto-occipital lobule is an important anatomic substrate for lexical agraphia.

Another group of agraphic patients is unable to spell correctly due to a breakdown in the interaction of semantics with the orthographic output lexicon (Heilman, Tucker, & Valenstein, 1976; Heilman, Rothi, McFarling, & Rottmann, 1981). This clinical disorder is termed semantic agraphia (Roeltgen, Rothi, & Heilman, 1982) and refers to the inability to spell and write on the basis of meaning. These patients may write semantically incorrect but correctly spelled homophones of the presented target word. For example, if asked to spell "heir" as it relates to an inheritance, they may spell "air." However, their intact nonlexical-phonological and phonological spelling/writing routes enable them to spell irregular words as well as nonsense words. The anatomic substrates of semantic agraphia include 1) a subcortical lesion involving the caudate, internal capsule, and frontal subcortical region, 2) the medial frontal and parietal areas, 3) hemispheric cortical watershed areas, and 4) the thalamus (Roeltgen, 1985).

Executive Agraphias

Within the legibility syndromes of agraphia there are two basic types: 1) central agraphias and 2) peripheral agraphias (Margolin, 1984). The most central level at which the writing process may be interrupted is at the physical letter code (Figure 1.1). The physical letter code, the

physical letter form determinant, subserves all visually-based spelling. Therefore, a lesion involving this level could affect handwriting as well as anagram spelling as well as typewriting. Kinsbourne and Rosenfield (1974) reported the case of a patient who suffered a left posterior parieto-occipital lesion resulting in an agraphia selective for written spelling. That is, the patient's spelling deficit was much more severe in the written modality than in the oral modality. It should be noted that this patient had as much difficulty spelling with anagram letters as in handwriting.

A different kind of agraphia results when a lesion spares the physical letter code and the graphic motor pattern but disrupts the transmission of information between these two codes. Separately, an intact physical letter code specifies which physical forms (e.g., lower case versus upper case letters) are acceptable versions of the letter previously specified in the orthographic buffer. An intact graphic motor pattern stores the motor programs which specify the sequence of strokes necessary to complete the form dictated by the physical letter code. Therefore adequate information from the physical letter code spares anagram spelling and typewriting while adequate information from the graphic motor pattern results in correct letter formation. Thus, a disconnection of information from the physical letter code (correct spelling) to the graphic motor

pattern (correct letter formation) results in the graphic motor pattern producing a high number of letter substitution errors, a spelling disorder limited to handwriting. Rothi and Heilman (1981) described such a spelling deficit in a patient who had alexia and agraphia with spared oral spelling, well-formed letters, improved spelling with copying and anagram letters but a high incidence of letter substitution errors.

A lesion that disrupts or influences the operation of the graphic motor pattern explains as least three subtypes of executive agraphia that have been described including apraxic agraphia, micrographia, and spatial agraphia. Each will be discussed separately.

When the praxis system is impaired, the result is a disorder in the execution of learned, skilled movements that cannot be explained by lack of comprehension or by inattention, sensory loss, weakness, ataxia, or basal ganglia disorder (Watson & Heilman, 1983). In the context of writing, impairment of the graphic motor program (Figure 1.1) results in an inability to perform the motor movements necessary for writing called apraxic agraphia. Attempts at writing by these patients yield illegible scribbles and they may be unable to correctly perform other previously learned, skilled movements such as pantomimes as well. There can be preserved ability to orally spell, to copy written material, to type and to use anagram letters. This subtype of

agraphia is characterized by illegible writing both from spontaneous production or from dictation. Apraxic agraphia usually is induced by lesions of the hemisphere opposite to the preferred hand.

Limb apraxia results from a disturbance of the motor engrams of skilled limb movements while apraxic agraphia results from a disturbance of the motor representation specific to grapheme production. Apraxic agraphia may also be seen even in the absence of ideomotor apraxia (Roeltgen & Heilman, 1983; Margolin and Binder, 1984; Coslett, Rothi, Valenstein, & Heilman, 1986) and limb apraxia may occur in the absence of apraxic agraphia (Coslett et al., 1986) suggesting that cerebral dominance for handwriting is not necessarily linked to dominance for other cortical functions. Specifically, and most relevant here, it should be noted that although limb apraxia and apraxic agraphia commonly coexist, they are not causally related (Roeltgen, Sevush, & Heilman, 1983; Coslett, Rothi, Valenstein, & Heilman, 1986) suggesting that limb apraxia and apraxic agraphia have distinct neuropsychological representations. Heilman, Coyle, Gonyea, & Geschwind (1973) described a left-handed patient who developed a left hemiplegia without aphasia who not only lost the ability to write with the right hand (which he had always used for this task) but also showed clear-cut apraxia of the right side following a large lesion of the right middle cerebral artery. Subsequently

Heilman, Gonyea, & Geschwind (1974) reported a related case in which a right-handed patient who suffered a left hemisphere lesion developed an apraxic agraphia of the left hand. This case suggests that while language was present in the left hemisphere, dominance for handedness was in the right hemisphere and that therefore in the normal act of writing the corpus callosum was traversed. The lesion in the hemisphere dominant for handedness destroyed the engrams for complex motor activities and was responsible for the apraxia and agraphia. That this syndrome was produced in a left-hander is not surprising since Goodglass and Quadfasel (1954) found that language was disturbed by left hemispheric lesions in 53% of left-handers. This high frequency of crossed aphasia in left-handers suggested to these authors that cerebral laterality for language and handedness are not directly linked and one does not determine the other.

Obviously, any peripheral motor disturbance such as weakness or tremor will disturb handwriting. Micrographia or abnormally small handwriting is one such disorder of handwriting that manifest itself in Parkinson's disease. Marsden (1982) attributes this handwriting disorder to an inability to distribute and maintain the force necessary to execute motor programs that help to maintain the proper letter height. Margolin and Wing (1986) report on a quantitative analysis of handwriting in Parkinsonian patients with micrographia who could produce appropriate

letter strokes but could not maintain adequate force to preserve letter size. Micrographia was found to be associated with an increase in movement time, thus, a decrease in effective force for writing. Margolin and Wing (1986) note that the increase in movement time was not adequate to compensate for the loss of force, however, and this resulted in a decrease in letter size. It was further noted, that as the Parkinsonian patients continued to write, the force diminished progressively, and the micrographia became more marked. This explanation of micrographia is consistent with the clinical observation that Parkinsonian patients have difficulty initiating and maintaining adequate force to execute movements. With respect to the model of handwriting control, these changes represent problems executing an intact graphic motor plan. That is, Parkinsonian patients with micrographia were able to access an intact graphic motor pattern but could not generate the proper neuromuscular activity to produce a letter or adequate size.

Micrographia was first noted by Pick (1905) in certain patients with localized cerebral disorders. McLennan, Nakano, Tyler, & Schwab (1972) defined the characteristics of this phenomenon in a large population (63 cases) of Parkinsonian patients. These patients are unable to sustain normal-sized writing for more than a few letters, if at all. There is also a tendency for the handwriting to have a left

to right slant accompanied by a progressive smallness as the end of the message or as the edge of the paper nears. Generally, micrographia is unique to Parkinsonism and commonly is its earliest sign.

Spatial agraphia (also termed "visuospatial agraphia" and "constructional agraphia") (Leischner, 1969) is a disturbance of written output based on impaired visual-spatial perception which leads to a breakdown in sensory feedback updating the graphic motor pattern as to which strokes have already been executed. Patients with this type of agraphia typically duplicate strokes (for instance, producing extra loops in "m" or "n"), have trouble writing on a horizontal line (write with an upward slant), write on only the right side of the paper, and inappropriately place blank spaces between letters (in a given word) (Roeltgen, 1985). It is frequently associated with the neglect syndrome (Hecaen & Albert, 1978; Marcie & Hecaen, 1979; Benson, 1979).

In summary, this literature suggests that there is a distinction in the nervous system between linguistic and legibility components of writing. Whether the legibility component subsyndromes imply that subsystems are represented in the nervous system in normals is of particular interest to the investigator. It is the intent of this investigation to examine aspects of the legibility of writing in nonbraindamaged individuals.

Statement of the Problem

Most right handers prefer to use their right hand when writing. The neuropsychological mechanism underlying this writing preference has not been completely determined. As noted previously, writing is a complex system encompassing multiple component systems to accomplish the process. Three specifically (linguistic, praxic, and motor) remain strongly lateralized in the nervous system, and because writing is dependent upon them, each may contribute to hand preference asymmetry as well as the lateralization of handwriting skill. Before discussing the possible contributions of each of these systems, the reason why hand preference for a task may reflect hemispheric superiority (motor control) will be discussed.

The two pathways participating in the cortical control of movement are the pyramidal and the extrapyramidal systems. The system that controls voluntary movements is called the pyramidal system. The fibers of the pyramidal tract directly affecting motor functions arise mainly from Brodmann's areas "4" and "6," motor cortex and supplementary motor cortex, respectively. These cortical projection fibers converge after leaving the gray matter to form the corona radiata. Continuing caudally, they pass through the internal capsule and make up the inner 3/5 of the cerebral peduncles of the midbrain. In the ventral pons, the fibers of the peduncle split into several bundles. At the caudal

border of the pons, the tract fibers reunite and enter the medulla as a distinct bundle in the medullary pyramids. In the lower medulla the motor or pyramidal decussation results in the formation of a large crossed lateral corticospinal tract that influences distal musculature. Approximately 10% of the fibers do not decussate and course in the medial portion of the ventral funiculus as the ventral corticospinal tract which affects the axial musculature. At the level of the internal capsule the lower limbs are located laterally while the upper limbs are located posteriorly. This organization is preserved through the pons and the medullary pyramids, and it emerges clearly in the spinal cord after decussation. The fibers enter the spinal gray and terminate on neurons of the intermediate zone or directly on motoneurons. The extrapyramidal system is involved in coordinating and regulating motor movements.

The presence of ipsilateral motor control of axial and proximal limb movements and contralateral motor control of axial, proximal, and distal limb movements has been demonstrated in both animals and man. Lawrence and Kuypers' (1968a and 1968b) studies described the brain's capacity to control limb movements in terms of its descending motor pathways. These motor pathways, the ventromedial brainstem pathway and the lateral brainstem pathway, allow for whole body movements as well as limb movements. The ventromedial brainstem tract group consists of the reticulospinal tracts,

vestibulospinal system, and the tectospinal system. The ventromedial tract group projects to and influences motoneurons supplying muscles of the axial skeleton and the limb girdle. Specifically, the ventromedial brain stem pathway is credited with integrated body-limb movements and whole body movements while the lateral brainstem pathway provides for movement of individual limbs, especially distal appendages. Based on these neuroanatomical findings, they hypothesized that, in the rhesus monkey, each half of the brain has full control over arm, hand and finger movements contralaterally, but ipsilaterally mainly controls arm movements.

Brinkman and Kuypers (1973) tested this hypothesis in split-brain rhesus monkeys with complete commissurotomy including the optic chiasm. The visual input was restricted to one half of the brain by covering one eye. They concluded that under visual guidance of one eye the contralateral hand and fingers had control of the finger movements necessary for the retrieval of small food pellets. That is, primates under guidance of the right eye were able to perform the necessary pinching movement with their left thumb and index finger in order to retrieve the food pellet. Under visual guidance of the left eye, the ipsilateral (left) hand and fingers, however, did not accomplish such movements. Instead the left hand and fingers remained fully flexed while searching "blindly" for the target (food

morsel). From these findings it was inferred that the seeing half of the brain does not provide the ipsilateral hand and fingers with the distal motor control necessary to carry out coordinated hand and finger movements.

In humans in which the corpus callosum had been transected (to help treat severe convulsive disorders), right hand superiority for making distal verbal and nonverbal movements has been documented (Sperry, Gazzaniga, & Bogen, 1969; Gazzaniga, 1970). That is, in the cases of two right-handed individuals no motor impairment was noted in tasks involving the contralateral limb. In general, motor peculiarities were reported in those activities in which a hemisphere was required to direct movement of the ipsilateral extremity. It should be noted, however, that good ipsilateral control was first attained for responses carried out by the axial and more proximal limb musculature (e.g. pointing). In fact, Sperry et al. (1969) noted that even writing with the left hand was possible when free shoulder movement was allowed. Brown, Leader, and Blum (1983) described the assistance of shoulder movement in hemiplegic writing of global aphasic patients. With sufficient limb rigidity to grip a pen holder, and sufficient proximal motility to drive the writing prosthesis, the patients of Brown et al. (1983) demonstrated an ability to write with the hemiplegic limb.

Tachistoscopic presentation of different hand positions flashed to the left hemisphere resulted in the patients readily mimicking the postures with their contralateral hand (right hand), but usually failing with their ipsilateral (left hand). However, it should be noted that simple postures such as making a fist and extending all fingers facilitated correct left hand performances. Also correct responses were obtained with the left hand when stimuli were presented to the right hemisphere. The greatest impairment noted in nonverbal testing involved right hemispheric control of the right hand in reproducing simple geometric figures. That is, when simple geometric shapes were flashed tachistoscopically to a patient's left visual field it required that his right hemisphere control the movements of his right hand. The resulting right hand drawing performances were characteristic of crude reproductions of the geometric figures and gross control of the right arm involving mostly proximal (shoulder) movements. At times the patients could also draw correctly with the right hand various simple geometric shapes presented to the left-half visual field. In summary, ipsilateral motor control is good in split-brain patients as long as one does not call into action the most distal musculatures of each limb.

This is particularly relevant to study since writing is normally a distally (finger/wrist movements) accomplished task. However, brain injured patients are known to utilize

proximal systems (shoulder movements) in order to compensate for their loss.

These studies in monkey and man suggest that motor control over the distal extremity of the preferred right hand such as that used for writing is best explained by some sort of left hemispheric superiority. The nature of this superiority has not been fully elucidated. There are however, one or more of the three functions previously discussed (praxis, language, and motor skill) that are candidates.

Review of the Literature of Three Possible Explanations

Motor Skill Superiority

One possible explanation for the superiority of distal movements by the right hand in right-handers could be that the right hand is simply more skilled at finely coordinated movements. In the past this "superiority effect" of the distal right extremity has been argued (from two extreme positions) as resulting from differential usage or natural innate motor superiority.

The simple task of rapid tapping with a single finger has been studied to show such differences in distal extremities. Differences in performance between the preferred and nonpreferred hands have been documented in a number of finger tapping motor skills studies (Provins,

1956; Satz, Achenbach, & Fennell, 1967; Barnsley & Rabinovitch, 1970; Provins & Cunliffe, 1972a; Flowers, 1975; Peters, 1976; Bowers, Heilman, Satz, & Altman, 1977; Peters & Durding, 1979; Johnstone, Galin, & Herron, 1979; Peters, 1980; Todor & Kyprie, 1980; Provins, Milner, & Kerr, 1982; Kee, Bathurst & Hellige, 1983; McManus, Kemp, & Grant, 1986). In those studies where the speed of tapping served as the dependent variable, results revealed a clear superiority of the preferred hand. Peters (1976) reported that in one right-hander the average tapping rate of the right index finger (56.8 sec) was significantly faster than that of the left index finger (49.9 sec). The same results have been substantiated by Bowers et al. (1977) in their study of 24 right-handed adults. Baseline measures of mean number of taps by right and left hands revealed that the right hand was faster (153.0 sec) than the left hand (137.0 sec).

In those investigations where both right-handers and left-handers were asked to perform the finger tapping test, the preferred hand did show better performance. Provins and Cunliffe (1972b) reported that when the mean performance between the two hands was compared, the preferred hand was significantly faster ($p < 0.001$) than the nonpreferred hand. The same preferred hand superiority has been reported by Peters and Durding (1979); Johnstone et al. (1979); Todor and Kyprie (1980); Peters 1980; Provins et al. (1982); and

McManus et al. (1986). However, not all tests of finger tapping speed reveal significantly better performance of the preferred hand. Satz et al. (1967) reported a better preferred hand performance for dextrals but not for sinistrals. That is, 87% of the right-handers demonstrated superior performance of their preferred hand while only 51% of the left-handers demonstrated superior performance of their preferred hand.

Hand superiority on activities requiring strength revealed discrepant findings regarding performance of the preferred hand. Provins and Cunliffe (1972b) reported that differences between the preferred and nonpreferred hands of 20 right-handed and 20 left-handed males on a test of grip strength were highly significant ($p < 0.001$). The mean performance indicated a stronger preferred hand performance for both right-handers (right hand--stronger) and left-handers (left hand--stronger). Johnstone et al. (1979); Provins et al. (1982); and Borod et al. (1984) reported similar findings of a superior preferred hand performance within handedness groups. To the contrary, while Satz et al. (1967) in their investigation of manual strength reported a markedly superior grip of the right hand in the dextral group they noted only a slightly stronger left hand in the sinistrals. Only 56% of the left-handers demonstrated superior preferred hand performance on the

dynamometer "grip" test while 87% of right-handers demonstrated superior preferred hand performance.

In a test of manual dexterity where subjects were required to pick up small pins with a tweezer, place them in a row of holes in a pegboard, and pick up small metal collars and place them over the pins (Small Parts Dexterity Test, Crawford & Crawford, 1956), researchers found different left hand versus right hand dexterity results of preferred hand performance. Provins and Cunliffe (1972a and 1972b); Johnstone et al. (1979); and Provins et al. (1982) describe greater dexterity of the preferred hand in their investigation of right-handed and left-handed individuals. Satz et al. (1967) reported that 75% of the dextrals showed superior preferred hand performance while 69% of the sinistrals showed superior preferred hand performance. Also, in a nine hole peg test of finger dexterity Mathiowetz, Kashman, Volland, Weber, Dowe, & Rogers (1985a) report a superior preferred hand performance for dextrals but not sinistrals. The same results were reported from an investigation of the box and block test of manual dexterity (Mathiowetz, Volland, Kashman, & Weber, 1985b).

Taken together these reports suggest that in right-handers, the right hand does have a motor advantage over the left hand while motor advantage of the dominant hand in left-handers remains unclear. Whether the advantage seen at

least in right-handers accounts for writing preference remains unknown.

Language

A second explanation for the left hemisphere-right hand preference for writing is that there is an association between language laterality and handedness. Indeed, handedness is the most widely used correlate of cerebral dominance for language. It is estimated that 90-99% of all right-handers have their language functions predominantly subserved by the left hemisphere (Searleman, 1977). The finding that in most people, language is represented predominantly in the left side of the brain has been documented in lesion studies. The first observation that the left half of the brain is concerned with the functions of speech and language is usually attributed to Broca (1861) although an unpublished manuscript relating defects of language and lesions of the left hemisphere was written by Dax in 1836. After observing 40 patients suffering from speech disturbances as a result of left hemisphere damage, Dax (1836) concluded that the left hemisphere controlled speech. Broca (1861) reported the case of an individual who presented with what was termed "Broca's aphasia" from a lesion of the left hemisphere and attributed the expressive components of the communication disorder to that portion of the lesion involving the frontal lobe. Subsequently Carl

Wernicke (1874) described the occurrence of Wernicke's aphasia as a consequence of lesions in an area in the upper, posterior part of the left temporal lobe (Wernicke's area) and conduction aphasia resulting from lesions between Wernicke's and Broca's areas. Subsequently, other forms of aphasia have been documented as resulting from damage to the left cerebral hemisphere of right handers.

While unilaterally brain damaged patients provide the classic source of data regarding language lateralization, other techniques have recently been devised which allow estimates to be made as to the hemisphere responsible for language as well. Some of these techniques are used with patients documented as having some kind of neurological deficit while others are used with neurologically normal subjects.

Injection of sodium amylobarbitone into the common carotid artery results in the drug being circulated through the cerebral vascular system. It has the effect of temporarily depressing the functions initially of the hemisphere on the side of the injection and subsequently of the opposite hemisphere. This is the basis of the test for hemispheric speech representation first described by Wada (1949). Rasmussen and Milner (1975) summarize data collected in their clinic over a number of years of using the Wada test (Wada & Rasmussen, 1960; Branch, Milner, & Rasmussen, 1964). Of the 140 right-handers tested, 96% had

speech controlled by the left hemisphere of the brain while only 4% demonstrated right hemisphere speech control. Among the left-handers, 70% had speech controlled from the left hemisphere while 15% had right hemisphere speech and 15% had speech represented bilaterally. Rossi and Rosadini (1967) also used the Wada test but reported that only 1 patient out of 74 right-handers did not have exclusively left hemisphere speech dominance.

Penfield and Roberts (1959) administered electrical stimulation to the exposed cortex in Broca's area and/or in inferior parietal and/or posterior temporal regions of the left hemisphere. This treatment was carried out during surgery for the relief of focal epilepsy. Of 65 right-handed patients, 64 showed a positive or negative affect to their speech during cortical stimulation. A positive effect means that electrical stimulation via the electrode elicits some vocalization whereas a negative effect either disrupts ongoing speech or produces an inability to vocalize or to use words properly. Stimulation of the left cortex positively affected speech in only 3 of 10 left-handed subjects. Stimulation of corresponding regions of cortex in the right hemisphere revealed that only 1 of 14 right-handers showed a negative effect of stimulation and only 1 of 6 left-handers showed a negative effect of stimulation. Penfield and Roberts (1959) concluded from their data that in nonbraindamaged individuals the left hemisphere is

usually dominant for speech regardless of the handedness of the individual.

Patients who have undergone complete section of the commissures linking the two hemispheres of the brain also provide an opportunity to verify that the left hemisphere is superior in language processing. Commissurotomy patients are able to name words or pictures presented to the right visual field, which projects to the left hemisphere, but they are unable to name words or pictures presented to the left visual field which projects to the right hemisphere. Similarly, they can name objects felt with the right hand but cannot name objects felt with the left hand (Gazzaniga, 1970; Gazzaniga & Sperry, 1967).

Since writing is one of the two major modes of linguistic expression, language is likely to have a profound influence upon the motor systems that produce writing. A callosal lesion could produce a disturbance of skilled distal movements by disconnecting the language area of the left hemisphere from the motor area of the right hemisphere that controls fine coordinated movements (such as those used for writing) of the left hand. Lesions of the corpus callosum not only disconnect the language hemisphere from the hemisphere controlling the left hand but also separate visuokinesthetic motor engrams which program skilled movement from the motor areas in the right hemisphere (Heilman & Valenstein, 1985). Geschwind and Kaplan (1962)

described a patient who suffered brain damage that led to destruction of the anterior four-fifths of the corpus callosum. The patient could not follow commands with his left hand but could correctly imitate and could use actual objects. Additionally, the patient was agraphic with the left hand and could not type or use anagram letters with the left hand but performed flawlessly with the right hand.

Gazzaniga et al. (1967) reported the motor symptoms of nine right-handed patients who had undergone complete cerebral commisurotomy. Tachistoscopic presentation of words to the right visual field (left hemisphere) of these patients resulted in words written with the left hand but with more hesitant, gross and crude movements than those produced with the right hand. Since language is mediated by the left hemisphere, the motor systems that control the right distal hand would have more direct access to linguistic knowledge than those that control the left hand. The motor systems controlling distal left hand may have to rely on callosal transfer of language information via a less direct and perhaps less efficient route therefore resulting in poor motor control during the handwriting task. However, the muscles that control the proximal muscles of the left arm may have a more direct access to the left hemisphere language systems, allowing an individual to use gross movements in order to accomplish any given handwriting task.

In order to study hemispheric specialization in neurologically intact subjects, a number of investigators have used electrophysiological techniques. Schafer (1967) reported finding significant electrical activity of the left temporal region of right-handers immediately prior to speech production. Subsequently McAdam and Whitaker (1971) demonstrated that prior to the production of various test words, summed negative wave potentials were of greater magnitude over the left than the right hemisphere of right-handers. Cohn (1971); Morrell and Salamy (1971); Morrell and Huntingdon (1972) presented evidence that summated auditory evoked potentials show a higher amplitude over the left hemisphere when right-handed subjects listened to monosyllabic words. However, differential waveforms were recorded over the left hemisphere of right-handers when a semantic analysis of the presented stimuli was required (Wood, Goff, & Day, 1971; Matsumiya, Tagliasco, Lombroso, & Goodglass, 1972). For example, Teyler, Roemer, Harrisson, & Thompson (1973) recorded evoked potentials when right-handed subjects simply thought of the meaning of words which could be used as either nouns or verbs. Significant differences were found within each hemisphere but an overall greater magnitude of response was recorded over the left hemisphere.

Considerable controversy still exists concerning the cerebral organization of speech and language functions in left-handed individuals. Penfield and Roberts (1959) showed

that transient aphasia occured in 73% of right-handers and 72% of left-handers following surgery on the left hemisphere. Moreover, cases of aphasia following surgery of the right hemisphere were not significantly more frequent in left-handers than in right-handers. Based on these results, Penfield and Roberts (1959) concluded that the left hemisphere is dominant for speech in the vast majority of right-handers and left-handers. More recent findings report a more variable pattern of cerebral speech dominance in left-handed individuals (Hecaen & Sauguet, 1971). Piercey (1964) and Warrington and Pratt (1973) in their studies of unilaterally braindamaged adults and nonbraindamaged psychiatric patients support a 66% left hemisphere speech dominance in left-handers. This contrasts, however, with Milner's (1973) report of hemispheric speech dominance in epileptic patients. It has been reported that 70% of left-handers have speech and language functions localized in the left hemisphere of the brain. Of the remaining 30%, it is suggested that half show right hemisphere control of speech, and half have speech represented bilaterally (Rasmussen & Milner, 1975). From these figures, one might conclude that the majority of left-handers are just like right-handers, while many of the others show a simple reversal of the pattern found in right-handers. Clinical and experimental data, however, suggest that the picture may be more complex.

Levy and Reid (1976, 1978) have suggested that handwriting posture along with handedness provides useful information about which hemisphere is controlling speech and language in an individual. They postulated that left-handers who use the inverted hand posture have speech and language abilities primarily in the left hemisphere, whereas left-handers who use the noninverted hand posture use their right hemisphere for speech/language. In the inverted posture, the hand is positioned above the line with the pencil pointing toward the bottom of the page. In the noninverted posture, the hand is positioned below the line with the pencil pointing towards the top of the page. See Figure 1.2 for examples of the two handwriting postures.

To test whether inverters are neuropsychologically different than noninverters, Levy and Reid (1976, 1978) tested right-handers with the noninverted handwriting posture (RH-N) and one right-hander with an inverted handwriting posture (RH-I) and groups of left-handers with both the noninverted handwriting posture (LH-N) and with the inverted handwriting posture (LH-I) on two tachistoscopic tests. One test required subjects to identify nonsense syllables flashed to the left or the right of fixation, and one required subjects to locate on a dot array in free vision the relative position of a dot flashed to the left or the right. Based on the results of their investigation of perceptual asymmetry on lateral verbal and spatial

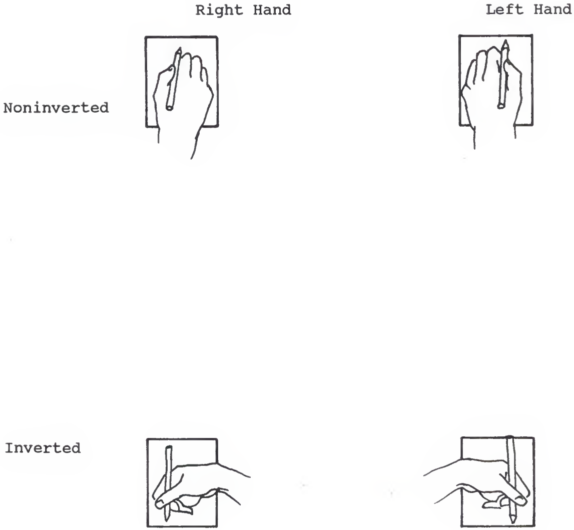


Figure 1.2. Handwriting postures: inverted and noninverted .

tachistoscopic tests in inverters and noninverters, Levy and Reid (1976, 1978) concluded that the left-handers who write with the "normal," noninverted posture have right-hemispheric language representation whereas those who write with the "hooked," inverted posture have left-hemispheric language representation. Moscovitch and Smith (1977) replicated Levy and Reid's study, using their tachistoscopic measure, with lateralized auditory, tactual, and visual stimulation. Results revealed that noninverters responded quickest to stimuli on the same side as the responding hand in all modalities tested, whereas inverted writers showed this pattern only in auditory and tactual modalities. In the visual modality, they responded quickest to stimuli on the side opposite the responding hand, suggesting that the differences in neural organization between inverted and noninverted left-handers lie primarily in the visual system or its interface with the motor system.

If most left-handers have language mediated by the left hemisphere and language superiority by itself determines writing hand, most of these left-handers should be writing with their right rather than their left hands. These findings do not allow us to conclude that language by itself dictates the writing hand.

Praxis

Studies of subjects with hemispheric and callosal injuries suggest that in right-handers the left hemisphere is not only dominant for language but also contains the space-time formulae responsible for controlling skilled limb movements (Geschwind, 1965; Goodglass & Kaplan, 1963; Hecaen & Ajuriaguerra, 1964; Hecaen & Sauguet, 1971; Heilman, 1975; Heilman, 1979; Heilman & Valenstein, 1985; Heilman, Gonyea & Geschwind, 1974; Heilman, Rothi & Valenstein, 1982; Liepmann, 1920; Liepmann & Maas, 1907; Kertesz & Hooper, 1982; Watson & Heilman, 1983) as well. Watson and Heilman (1983) described a right-handed individual who presented with apraxia and apraxic agraphia of the left hand after suffering a spontaneous corpus callosum disconnection. During the patient's recovery, her apraxic disorder of the left hand evolved from ideational apraxia to verbal-motor disconnection with ideomotor apraxia and finally to ideomotor apraxia. Heilman, Rothi, and Watson (1987) define ideational apraxia as a conceptual disorder where a brain-damaged patient has lost knowledge related to tool use. In the initial course of the illness this patient's apraxia was characterized by her inability to perform pantomimes to command, imitate pantomimes, demonstrate the intended use of objects or use actual objects with her left hand. When asked to pantomime skilled acts with her left hand, she looked at her left hand and alternately pronated and

supinated her hand or flexed and extended her fingers. The patient's left hand performance during imitation or with actual object use was precisely the same as it was to command. However, her right hand performance on pantomime to command, imitation, and actual object use was normal. The conclusion of Watson and Heilman (1983) was that the concepts of what objects are used for were not destroyed but were disconnected from the right hemisphere as manifested by her normal right hand peformance.

Twenty-five days after the haemorrhage the patient was still unable to perform pantomimes to command but showed some improvement in imitating pantomimes and using actual objects. The responses to imitation and actual object use tasks were described by the investigators as containing "spatiotemporal movement errors". For example, Watson and Heilman (1983) note that while demonstrating the use of a key their patient moved her left hand forward but did not follow with the turning movement of the wrist. This inaccuracy of her pantomime to command coupled with her ability to demonstrate the intent of object usage suggested to Watson and Heilman (1983) that at this point in her recovery the callosal lesion yielded a verbal-motor disconnection. Approximately seven weeks after the haemorrhage the patient presented with ideomotor apraxia and apraxic agraphia confined to the left hand. The patient was able to pantomime with her left hand in response to a

command, however, her pantomime performance was apraxic. Her performance with actual object use and imitation was better than that with pantomime, but remained apraxic. The patient's writing disturbance, apraxic agraphia of the left hand was characterized by an inability to write but preserved ability to type.

Liepmann (1908) has suggested that it is the lateralized "movement formula" that may underly hand preference. As discussed, studies of patients with apraxic agraphia also suggest that the movements needed for writing are also mediated by the left hemisphere. Perhaps it is these lateralized movement representations for letters that underlie the right hand superiority for making distal writing movements.

Statement of Purpose

Brinkman and Kuypers (1973) demonstrated that while distal limb movements are controlled by the contralateral hemisphere the more proximal limb movement may be controlled by the ipsilateral as well as the contralateral hemisphere. Since the work of Paul Broca, it has been repeatedly documented that in right-handers, it is the left hemisphere that mediates language. Similarly, since Liepmann's descriptions of apraxia it has been repeatedly demonstrated

that the left hemisphere in right-handers plays a dominant role in programming skilled movements.

If in right-handers language and skilled movements are programmed by the left hemisphere, and if the left hemisphere motor system controls the distal movement of the right forelimbs as well as the proximal movements of both forelimbs; then when a right-hander is asked to write with his right forelimbs he may use either distal or proximal movements. However, when asked to write with the left hand, right-handers may have to rely on more proximal arm movements since ipsilateral motor control is limited to the proximal movements. We performed the following experiment to test the hypothesis.

Eight normal subjects were studied. They ranged in age from 24 to 54 years. All subjects were right-handed with six of the eight having right-handed parents. The remaining two both had left-handed fathers. Each subject was individually tested by the same examiner in a quiet room without interruption. The subjects were seated facing a video camera and videotaped while they pantomimed writing the following words: cup, watch, house, telephone, and screwdriver. They were instructed to pretend to write each word on a sheet of paper situated vertically in front of them. Each word was written first with the right hand then with the left hand. Subjects were given pencils to use in

order to facilitate ease of the pantomime. There were ten trials on this task.

If a subject uses distal movements to write then there would be little vertical movement of the elbow. If a subject uses proximal movements to write, then one would expect large vertical elbow movements. Therefore, our dependent variable was vertical elbow movements.

We trained two observers to use a subjective rating scale. The rating scale was based on a score of 1 to 5, measuring the amplitude of the individual vertical elbow movements. Vertical amplitude was determined by the amount of movement of each individual's elbow from the place of rest. That is, the total movement of the subject's elbow while he wrote each word was considered vertical amplitude. Two observers (naive to the research question) were trained to rate vertical elbow movements according to our devised scale. After four days of training they rated each subjects' handwriting performance.

The mean rating for the group on elbow excursion when writing with the right hand was 2 and of the left hand was 3. On each trial, comparisons of right to left elbow excursion revealed that elbow movement was greater when the left hand was writing in 38/40 trials, greater with the right hand in 1/40 trials and equivalent in 1/40 trials. Our results support Brinkman and Kuypers' (1973) postulate by providing evidence that the left hemisphere influences

the distal right extremity and the proximal left extremity. Three possible explanations for the differences in their right and left hands include the following:

1. Distal movements require finer, more coordinated movements. Normal right handed individuals use distal and proximal musculatures of the right extremity when writing as opposed to using the proximal musculatures of the left extremity when writing because the right hand is more skilled in making fine, coordinated movements.
2. The distal, as opposed to proximal movements of handwriting are intimately tied to language. Because language is typically lateralized on the left, only the right hand is capable of distal handwriting production.
3. Assuming that the distal components of handwriting require or interface with the mechanism mediating all skilled hand movement in normals, and that the left hemisphere programs skilled hand movement in general, then the right hand would show skilled distal handwriting while the left hand would not.

Therefore, the purpose of this study is to learn whether language dominance, motor dexterity or lateralized skilled praxis engrams determine distal hand superiority of right hand over left hand during handwriting.

Experimental Questions

In order to learn whether language dominance, motor dexterity or lateralized skilled praxis engrams determine distal hand superiority of right hand over left hand during handwriting right-handed and left-handed subjects will be studied with writing, drawing and tracing tasks. Additionally, since it has been reported that left-handers differ in their cerebral organization according to hand posture (Levy and Reid, 1976), Left-Handed Inverters (LH-I) and Left-Handed Noninverters (LH-N), along with Right-Handed Noninverters will comprise the three groups of subjects being studied. In the verbal task the subjects will be asked to write words with both the right and left hand.

1. If it is the linguistic nature of the left hemisphere that drives the distal v. proximal musculatures for writing, then there should be differences in the performance of right-handers and left-handers. Right-handed persons should use predominantly distal (wrist/fingers) movements when writing words with the right hand and predominantly proximal (shoulder) movements when attempting to write words with the left hand. Since estimates are that 70% of the left-handed population have language housed in the left hemisphere while half of the remaining 30% show evidence of bilateral language representation and the other half show evidence of right hemispheric language

representaion, then based on the language hypothesis at least 70% of the left-handed subjects would be expected to perform like right-handers in the writing task. Moreover, since it has been postulated that Left-Handed Inverters have language housed in the left hemisphere, Left-Handed Inverters would all be expected to perform like right-handers on the writing task.

However, if either of the motor hypotheses are correct, then the subjects of this study are not expected to perform on the basis of their handwriting posture but rather on the basis of their handedness. That is, Left-Handed Noninverters and Left-Handed Inverters would be expected to perform in a manner opposite of Right-Handed Noninverters - they would use distal and proximal movements of their left arm when writing words but mainly proximal of the right arm. See Table 1.1.

2. If it is the lateralized motor control or praxis system rather than language that underlies the right/left proximal distal asymmetry, then one should see these asymmetries with nonverbal material such as nonsense shapes. As previously mentioned, if the motor system of the left hemisphere is the mechanism behind these asymmetries, Right-Handed Noninverters, Left-Handed Inverters, and Left-Handed Noninverters would be expected to perform exactly alike but in opposite directions. That is, all subjects should use distal

Table 1.1

Summary Table of Right Hand/Left Hand Distal-Proximal Asymmetry Predictions in Right-Handed Noninverters (RH-N), Left-Handed Noninverters (LH-N), and Left-Handed Inverters (LH-I) based on the 1) Language Dominance Theory, 2) Internal Praxis Representation Theory, and 3) Motor Skill Superiority Theory

Theory	Writing Words			Drawing Figures			Tracing		
	RH-N	LH-N	LH-I	RH-N	LH-N	LH-I	RN-N	LH-N	LH-I
Language Dominance	+	+	+	-/o	+	-/o	o	o	o
Praxis	+	+	+	+	+	+	o	o	o
Motor	+	+	+	+	+	+	+	+	+

+ = distal movement - preferred hand
proximal movement - nonpreferred hand

- = distal movement - nonpreferred hand
proximal movement - preferred hand

o = no differences between preferred and nonpreferred hand

contralateral movements when drawing with their preferred hand and shoulder movements when asked to draw the same figures with their nonpreferred hand. See Table 1.1.

The motor and praxis theories may be more difficult to dissociate. Unlike spontaneous writing or reproductions which are open looped, tracing is closed loop and may not require movement (praxic) representations.

3. If the right-left proximal-distal asymmetry Mack et al. (1987) observed was related to motor dexterity, when asked to simply trace words and geometric figures, Right-Handed Noninverters would be predicted to perform with distal movements while using the right hand and proximal movements while using the left hand. Left-Handed Noninverters and Left-Handed Inverters, on the other hand, would be expectd to show the opposite pattern. While tracing with the left hand, distal movements should dominate while proximal movements should characterize the tracing performance of the right hand. If, however, internal praxic representations are responsible for the preponderance of distal movements with contralateral preferred hand as opposed to the ipsilateral non-preferred extremity, the same asymmetries should not be seen with tracing as those seen with spontaneous writing or drawing or with copying. See Table 1.1.

CHAPTER 2

METHODS

To learn whether language dominance, motor dexterity or lateralized skilled praxis engrams determine distal hand superiority of right hand over left hand during handwriting, right-handed and left-handed subjects were studied with writing, drawing and tracing tasks. These three tasks were designed to permit examination of hemispheric specialization of distal versus proximal hand movements. In the first task, the influence of language on handwriting performance was evaluated; while the second task focused on the influence of the lateralized praxis system on drawing performance; and the third task allowed investigation of the influence of motor dexterity on handwriting and drawing performance. All stimuli were presented as words and/or nonsense geometric figures and viewed by participants for approximately five seconds. Subjects were asked to reproduce (write and/or draw) each presented stimuli on a plexiglass board. Vertical elbow amplitude of the writing hand served as the dependent measure.

Subjects

The subjects included in the study were right-handed and left-handed young adults who had no history of central nervous system damage. Subjects were further divided according to their handedness classification and the hand posture used during writing: inverted hand position (IHP) and noninverted hand position (NHP). As a result, three distinct groups of subjects were selected: 1) Right-Handed Noninverters (RH-N), 2) Left-Handed Noninverters (LH-N) and 3) Left-Handed Inverters (LH-I). See section entitled Posture below for further explanation of handwriting positions. A total of 36 subjects were included in the study: twelve NHP right-handed individuals, twelve left-handed IHP individuals, and twelve NHP left-handed individuals. Sex, age, family handedness, and level of education were recorded and matched across groups. Appendix A contains information related to each individual's age, years of formal education, handedness, and familial history of handedness.

Hand Posture

The inverted hand position (IHP) is one in which the hand is held above the line and the pencil points toward the bottom of the page. The noninverted position (NHP) is one in which the hand is held below the line and the pencil points toward the top of the page (Levy and Reid, 1976). See Figure 1.2

for examples of the two writing positions. Hand posture was assessed while each subject wrote his name and address on a lined 8 1/2 x 11 sheet of paper, slanting the paper or tilting his head as he wished. No right-handers with inverted hand position were included in the study.

Handedness Classification

Handedness was determined by self report of the preferred writing hand, however, each subject was given the Waterloo Handedness Questionnaire II (Steenhuis and Bryden, 1988). See Appendix B for a copy of the Waterloo Handedness Questionnaire II. This 60-item hand preference questionnaire samples tasks that require movement of either the proximal musculature (arm and shoulder and/or body axis) or the distal musculature (finger and/or hand). Some items involve the picking up of an object, while the other items involve the manipulation of that object. Subjects were asked to rate their hand preference on a 5-point scale. For each item, subjects indicated that they (1) always use their left hand; (2) usually use their left hand; (3) use either hand; (4) usually use their right hand; or (5) always use their right hand. A total score of 60 indicates a strong preference for the left hand while a score of 300 indicates a strong preference for the right hand. From the questionnaire data, those persons receiving a score of 180 or more were classified as right-handed and those receiving

a score of less than 180 were classified as left-handed (Steenhuis and Bryden, 1988).

Stimulus Materials

Task I: Writing Task. The stimuli of the writing task consisted of 20 words written on 5 x 7 index cards. Words for this task were derived from various combinations of the small cursive letters "a", "c", "e", "m", "n", "o", "r", "s", "u", "v", and "w". These letters, characteristic of uninterrupted, continuous ascending and descending strokes, allowed the subject to write the verbal stimulus within the confines of the designated writing space. The following words were used: "cows", "vane", "seam", "curve", "omen", "sour", "more", "room", "vase", "warm", mace", "uses", "come", "once", "rose", "sane", "wear", "mane", "race", and "norm". Each word was written in small cursive letters, approximately 3/4 in. apart and 1 in. high. The writing test consisted of four training trials and 20 test trials.

Task II: Drawing Task. The drawing task consisted of 20 nonsense geometric shapes drawn on 5 x 7 index cards. See Figure 2.1 for the stimuli of the drawing task. The nonsense geometric figures found in Figure 2.1 were designed and selected by the investigator with the following specifications: 1) they are drawn with flowing strokes resembling handwriting and 2) unlike traditional geometric figures (e.g., triangle, square, circle, etc.), they do not

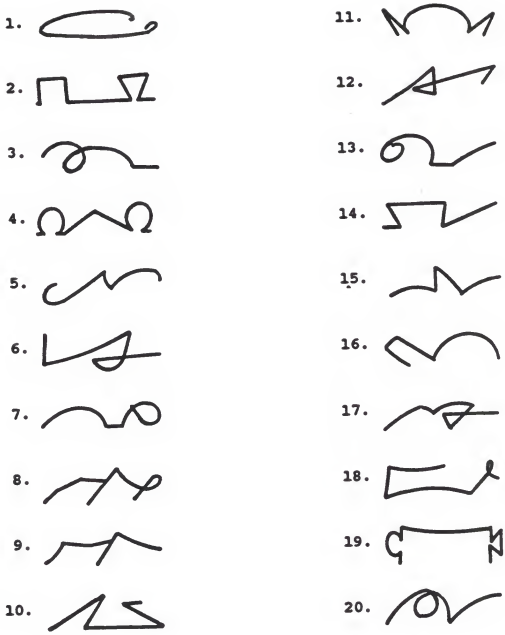


Figure 2.1. Nonverbal task: Nonsense geometric figures.

contain an immediate linguistic component. Nonsense figures were used instead of traditional geometric figures in order to maximize the likelihood that the subject's response be nonverbal and therefore less likely to be influenced by the linguistic content of the stimuli. However, it should be noted that all of the drawing stimuli chosen for this task are probably not free from verbal labelling. The drawing test also consisted of four training trials and 20 test trials.

Task III: Tracing task. A tracing task consisting of the previously mentioned writing and drawing stimuli were presented to each participant. The tracing test consisted of four training trials and forty test trials. Twenty words and twenty nonsense geometric figures were written on 8 1/2 x 11 transparent sheets.

Apparatus

All writing, drawing, and tracing responses were recorded on a vertical plexiglass board. This plexiglass board was constructed out of a transparent 36 inches high x 48 inches wide piece of plexiglass, securely mounted in a 38 inches high x 49 inches wide, wooden casing. A grid (lines drawn (permanently), approximately 1/2 inch apart) covered the plexiglass board except for the center of the board. In the center of the board was the "writing block". This "writing block" consisted of two parallel, 4" horizontal

lines placed 1 inch apart. Additionally, four vertical lines (3/4 inch apart) were positioned inside the horizontal lines, extending from one end to the other. See Figure 2.2. The board is firmly bolted to a wooden pedestal equipped with locking casters to assure stability of the writing apparatus during testing. The entire structure stands 2 feet 5 inches from the floor to the bottom of the board and 6 feet 7 inches from the floor to the top of the board.

A Panasonic Professional/Industrial Video VHS Reporter, Model #CP-7U, color video camera/recorder was mounted onto a Panasonic Model VP 100 tripod for the purpose of videotaping subjects' performances.

Procedures

Subjects were seated on a stool (approximately two feet from the floor) with both feet placed firmly on the floor. The plexiglass board was positioned in the frontal plane within arm's reach of the subject and the videocamera was placed behind the board. All patients were tested by the same examiner in the same quiet room; free from distraction. The examiner asked the subjects 1) to write words, 2) to draw nonsense geometric figures, or 3) to trace words and nonsense geometric figures with either their preferred hand or their nonpreferred hand. All subjects performed all tasks with both hands, however, the order of presentation of tasks was counterbalanced across subjects and across

Figure 2.2. Handwriting Apparatus.

conditions to balance for order effects that may lead to confounding results. Within the tracing task, word and geometric figure stimuli were randomized. See Table 2.1. and Appendix C for order of task presentation. The subjects were given a black felt tip pen, were shown target stimuli for 5 seconds on the 5 x 7 index cards and were asked to reproduce these stimuli as precisely as possible. For the tracing task, a transparent sheet was taped to the plexiglass board for each trial. They were instructed to write/draw/trace within the confines of the "writing block". Subjects' writing, drawing, and tracing movements were videotaped through the plexiglass for later viewing and scoring.

Scoring the Tapes

Two observers were trained to use a subjective rating scale in order to report qualitative differences between subjects' hand performances. The rating scale was based on a score of 1 to 5, measuring the amplitude of the individual vertical elbow movements. A rating of 1 indicated minimum vertical amplitude ("hardly any movement"); 2--minimum to moderate vertical amplitude; 3--moderate vertical amplitude ("average amount of movement"); 4--moderate to maximum vertical amplitude; and 5--maximum vertical amplitude ("a lot of movement"). Vertical amplitude was determined by the amount of movement of each individual's elbow from the place of rest. That is, the total movement of the subject's elbow

Table 2.1.

Counterbalance design of subjects and conditions.

Subjects	Conditions		
S1	W	D	T
S2	D	T	W
S3	T	W	D
S4...	W	D	T...

Key: W = Writing
D = Drawing
T = Tracing

while he wrote a word, drew a figure or traced a word or figure was considered vertical amplitude. Two observers (naive to the research question) were trained with the aid of a handwriting training tape (devised from the Mack, Heilman and Rothi, 1987 study) to rate vertical elbow movements according to the devised scale. For the first two days of training (approximately eight hours), the raters watched videotapes of normal subjects' handwriting performances. At this time they set the scoring guidelines by mutual agreement of perceived amount of subject elbow movement and a corresponding degree of the rating scale. The next five days (approximately 20 hours) were spent viewing and scoring additional videotapes of normal subjects' handwriting performances and discussing scoring reports. After seven days of training (approximately 28 hours) they rated each subject's handwriting, drawing and tracing performances.

Human observers were used to rate handwriting behavior in order that their recorded data would reflect the qualitative aspects of the participant's left versus his right hand performance. Specifically, the investigator was concerned with the magnitude or spatial dimensions for the movement of subjects' left hands and right hands. The number of judges employed in the study was determined based on the concept of effective reliability (Ekman and Scherer, 1982). That is, two judges were used to perform the ratings

in order to allow the investigator the convenience of a correlation coefficient of equivalence as an appropriate index of reliability. The correlation coefficient of equivalence reflects the consistency (or inconsistency) of scoring between the two raters for all right hand performances and all left hand performances.

Judgments based on physical units of measurement are often more reliable than are judgements based on psychological units of measure. As a more practical and precise method of recording and analyzing the handwriting data, a third observer (naive to the research question) scored the tapes in order to determine the quantitative magnitude of the differences (if any) reported by the raters. This second scoring system was metric measurements. With the aid of a metric ruler, the third observer measured (in centimeters) the amount of each individual's elbow from the place of rest. The total amount (cm) of movement was then divided by the total number of descending and ascending strokes the subject produced while writing, drawing or tracing in order to arrive at an average vertical amplitude. For example, when measuring elbow amplitude while a subject wrote the word "uses" the total amount of subject's elbow displacement from the point of rest was divided by 9 (the total number of descending and ascending strokes for the word, "uses") in order to arrive at a quantitative score for that particular word.

Analyses

The experimental design of this study is a completely randomized block design with a 3 x 3 x 2 factorial experiment. The three blocks consisted of (1) right handed subjects, (2) left handed IHP subjects, and (3) left handed NHP subjects. Six treatments were defined as (1) writing with the dominant hand, (2) writing with the nondominant hand, (3) drawing with the dominant hand, (4) drawing with the nondominant hand, (5) tracing with the dominant hand, and (6) tracing with the nondominant hand. A repeated measures analysis of variance (ANOVA) was performed on between group ratings and pairwise comparison t-tests were performed within treatment ratings. The within-subject variable was right hand vs. left hand and the between-subject variable was writing vs. drawing vs. tracing. Descriptive statistics were performed between treatments in order to qualitatively analyze movement differences according to conditions. Additionally, an analysis of variance was performed between groups and within-treatments.

The sample size was determined to be 36 based on the following information:

a. variability of measurement: 3 cms
b. type of inference: hypothesis testing using a 1-tailed test
c. confidence coefficient level: 95%
d. power of the test: 90%

e. alpha level: .05

Therefore, 36 persons were used in this randomized complete block design to determine whether there is a .05 difference in vertical right v. vertical left elbow movement.

CHAPTER 3

RESULTS

This study was conducted to evaluate the influence of language, praxis skills, and motor superiority on distal-proximal handwriting movements. Contrasts between the nature of the task (writing, drawing, and tracing), hand used to perform the task (right hand versus left hand), and subject handedness and writing posture (Right-Handed Noninverters [RH-N], Left-Handed Noninverters [LH-N], and Left-Handed Inverters [LH-I]) were investigated. Thirty-six subjects were assigned to one of three handedness/hand posture groups and to each experimental condition. Responses consisted of vertical elbow amplitude displacement while writing words, drawing figures, and tracing words and figures with the preferred hand and nonpreferred hand.

Overview of the Analysis

The data obtained in the present study were subjected to four major analyses: 1) descriptive statistics on overall qualitative rating scores by groups, tasks and hand used to perform the task; 2) pairwise t-tests on individual qualitative rating scores within groups and hand used to

perform the task across tasks; 3) repeated measures analysis of variance on overall metric scores by groups, tasks and hand used to perform the task; and 4) pairwise t-tests post hoc comparisons on individual quantitative scores within groups and hand used to perform the task across tasks.

The first set of measurements, the qualitative rating scores were analyzed with the use of descriptive statistics. Means and standard deviations were calculated according to group (Right-Handed Noninverters [RH-N], Left-Handed Noninverters [LH-N] and Left-Handed Inverters [LH-I]), task (Writing, Drawing and Tracing) and by hand used to perform the task (right hand [Rhand] v. left hand [Lhand]).

Preliminary Analyses

Two preliminary procedures were undertaken to prepare subject responses for statistical analyses. These included inter-rater reliability testing and normality testing. A brief discussion follows.

Inter-rater Reliability

The handwriting videotapes were rated by two judges who were naive to the priori hypotheses to be tested as well as to the neuropsychological literature that deals with handwriting. In order to test inter-rater reliability, the Guttman Split-Half reliability method was used. This type of reliability testing yields a coefficient of equivalence

or a measure of the consistency of two observers measuring the same skill. Here, the results of the videotape scoring were divided into two equal parts (videotape scores from Judge #1 and videotape scores from Judge #2), and three within task comparisons were made between the two judges' scoring of patients' left and right hand performances. Only when performances on the two halves are highly correlated, reliability of measurement is assumed. Unfortunately, overall reliability coefficients were low, ranging from -.39 to .33, suggesting that the test of reliability across judges is unreliable because of possible differences in the way that the judges rated hand movements. See Table 3.1 for coefficients of equivalence for split-half reliability testing.

However, it should be noted that higher coefficients of equivalence were computed when patients' hand performances were separated and treated as separate entities. Again the reader is referred to Table 3.1. Resulting coefficients for right hand performances and left hand performances ranged from .78 to .87 and from .89 to .96, respectively. These high correlations suggest that the two judges were very close in their ratings of separate hand performances. Therefore, overall reliability testing between judges is unreliable due to the following possibilities: 1) differences in judges' scorings and/or 2) differences in subjects' hand performances. As a result, due to the low

TABLE 3.1

Split-Half Reliability Coefficients of Equivalence of Subjects' Assigned Rating Score Based on Amount of Vertical Elbow Amplitude While Performing the Three Experimental Tasks

Variable	Coefficient of Equivalence
WORDS	**0.33**
RWords	0.87
LWords	0.96
FIGURES	**-0.39**
RFigures	0.78
LFigures	0.93
TRACING	**0.02**
RTracing	0.83
LTracing	0.89

*coefficients of equivalence are based on the average score of each variable assigned by Raters #1 and Rater #2.

overall reliability correlations, reliability of ratings could not be assumed. Separate means were computed for right hand and left hand performances and used in data analysis. It should be further noted that the results of data analysis of the Qualitative Rating Scores should be interpreted as resulting from differences between the subject's hand performances or differences between Raters' scoring.

Test of Normality

Before proceeding with the analysis of the measurments, normality testing was performed in order to detect any distribution of errors of measurement. A univariate procedure by task and by hand used to perform the task revealed that the normality assumption was met in all cases.

Analysis of Qualitative Rating Scores

Overall Task Scores

Collapsing across subject groups, the means and standard deviations of judges' perception of subject performance on each type of task are presented in Table 3.2. The results of this analysis revealed that overall ratings for the three tasks included in the study did not differ significantly from each other. That is, significantly more movement was not noted when subjects performed the writing

TABLE 3.2

Summary Table of Judges' Ratings of Mean Amount of Vertical Elbow Amplitude on The Three Experimental Tasks.

TASK	MEAN	SD
Writing Words	2.07	0.25
Drawing Figures	2.03	0.16
Tracing	2.05	0.14

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

task (x = 2.07) than when performing the drawing task (x = 2.03) or when performing the tracing task (x = 2.05).

<u>Group x Task Scores</u>

Looking at the judges' ratings of subject group performance, means and standard deviations of each subject group (RH-N, LH-N and LH-I) by task (Writing, Drawing and Tracing) are presented in Table 3.3. The results of this analysis revealed that when instructed to perform the writing task, Right-Handed Noninverters had a mean perceived movement score of 2.16, Left-Handed Noninverters had a mean perceived movement score of 2.03 and Left-Handed Inverters had a mean perceived movement score of 2.04.

Results of judges' ratings of group performances on the drawing task (drawing nonsense geometric figures) revealed that Right-Handed Noninverters had a mean perceived movement score of 2.10, Left-Handed Noninverters had a mean perceived movement score of 1.96 and Left-Handed Inverters had a mean perceived movement score of 2.04.

On the tracing task (tracing words and nonsense geometric figures) results of judges' ratings of group performances revealed that Right-Handed Noninverters had a mean perceived movement score of 2.10, Left-Handed Noninverters had a mean perceived movement score of 2.02 and Left-Handed Inverters had a mean perceived movement score of 2.02.

TABLE 3.3

Summary Table of Judges' Ratings of Amount of Vertical Elbow Amplitude of Subject Groups on The Three Experimental Tasks.

TASK	SUBJECT GROUP		
	RH-N	LH-N	LH-I
WRITING WORDS	2.16 (0.39)	2.03 (0.12)	2.04 (0.12)
DRAWING FIGURES	2.10 (0.23)	1.96 (0.11)	2.04 (0.08)
TRACING	2.10 (0.22)	2.02 (0.08)	2.02 (0.06)

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

Group x Hand Used x Task

Writing words

Means and standard deviations based on a classification of subject group by hand used to perform the task within a given task are presented in Table 3.4. The results of pairwise comparison t-tests revealed that Right-Handed Noninverters made significantly more perceived elbow movements when writing words with their nondominant, left hand ($x = 2.38$) than when writing the same words with their dominant, right hand ($x = 1.94$) ($P = 0.002$). Left-Handed Noninverters did not differ in their perceived elbow movement when writing identical words first with their nondominant, right hand ($x = 2.00$) and dominant, left hand ($x = 2.05$). That is, there was no significant differences in the judges' ratings of hand performances for Left-Handed Noninverters ($P = 0.3019$). The Left-Handed Inverters showed significantly more perceived movement with their right elbow when writing words with their nondominant, right hand ($x = 2.10$) than when writing words with their dominant, left hand ($x = 1.98$) ($P = 0.0168$).

Drawing figures

For the drawing task means and standard deviations of each subject group by hand used to perform the task within the drawing task see Table 3.5. Right-Handed Noninverters made significantly more perceived movement with their elbows when drawing figures with their nondominant, left hand

TABLE 3.4

Summary Table Qualitative Rating Scores of Subject Group's Perceived Right Hand Versus Left Hand Performance on The Writing Task

SUBJECT GROUP	HAND USED TO PERFORM TASK		
	R HAND	L HAND	PR > /T/
Right Hand - Noninverters	x = 1.94 SD = 0.22	x = 2.38 SD = 0.41	0.0002**
Left Hand - Noninverters	x = 2.00 SD = 0.08	x = 2.05 SD = 0.15	0.3019
Left Hand - Inverters	x = 2.10 SD = 0.13	x = 1.98 SD = 0.08	0.0168*

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

*P<.05
**P<.01
***P<.001

TABLE 3.5

Summary Table of Qualitative Rating Score of The Three Subject Groups' Perceived Right Hand Versus Left Hand Performance on The Drawing Task

SUBJECT GROUP	HAND USED TO PERFORM THE TASK		
	R Hand	L Hand	PR >/T/
Right Hand - Noninverters	x = 1.94 SD = 0.22	x = 2.28 SD = 0.19	0.0001***
Left Hand - Noninverters	x = 1.98 SD = 0.11	x = 1.94 SD = 0.11	0.2521
Left Hand - Inverters	x = 2.10 SD = 0.09	x = 2.00 SD = 0.03	0.0025**

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

*$P<.05$
**$P<.01$
***$P<.001$

(x =2.28) than when drawing with their dominant, right hand (x = 1.94) (P = 0.0001). In the drawing task, Left-Handed Noninverters showed virtually equal perceived movements when drawing figures with their dominant, left hand (x = 1.94) and nondominant, right hand (x = 1.98) (P = 0.2521). On the other hand, Left-Handed Inverters demonstrated significantly more perceived movement with their right elbow when drawing figures with their nondominant, right hand (x = 2.10) than when drawing figures with their dominant, left hand (x = 2.00). This reported difference in judges' ratings of perceived hand performance was significant at the P = 0.0025 level.

Tracing words and figures

For the tracing means and standard deviations of performances of each subject group by hand used to perform the task within the tracing task see Table 3.6. Again, as previously reported in the first two tasks, the Right-Handed Noninverters made significantly more perceived movements with their nondominant, left hand (x = 2.26) than with their dominant, right hand (x = 1.96) when asked to trace words and figures (P = 0.0001). The Left-Handed Noninverters performed virtually the same with both the right hand (x = 2.02) and the left hand (x = 2.03) on the tracing task (P = 0.5800). Left-Handed Inverters, however, performed with slightly more movement with their nondominant, right hand (x = 2.05) when tracing as compared to their tracing

TABLE 3.6

Summary Table of Qualitative Rating Scores of The Three Subject Groups' Perceived Right Hand Versus Left Hand Performance on The Tracing Task

SUBJECT GROUP	HAND USDED TO PERFORM THE TASK		
	R HAND	L HAND	PR > /T/
Right Hand - Noninverters	x = 1.96 SD = 0.10	x = 2.26 SD = 0.20	0.0001***
Left Hand - Noninverters	x = 2.02 SD = 0.07	x = 2.03 SD = 0.10	0.5800
Left Hand - Inverters	x = 2.05 SD = 0.07	x = 2.01 SD = 0.04	0.0513

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

*P<.05
**P<.01
***P<.001

performance with their dominant, left hand (x = 2.01) (P = 0.0513). Table 3.7 summarizes the data by group and handedness of tasks within all tasks.

Analysis of Quantitative Scores

The quantitative scores for the three experimental tasks (writing, drawing and tracing) were initially analyzed using a repeated measures analysis of variance (ANOVA) to assess the explanatory power of any differences of the three independent variables (writing words, drawing figures and tracing words and figures) and hand used to perform the task (right hand v. left hand) between subject groups and within the three subject groups. In addition, descriptive statistics was performed using a univariate procedure in order to report means and standard deviations as well as test for normality.

Results of a repeated measures analysis of variance (ANOVA) of Group (RH-N, LH-N and LH-I), Task (Writing, Drawing, and Tracing) and Hand Used to Perform the Task (right hand v. left hand) revealed a significant interaction among Group, Task, and Hand Used to Perform the Task (P = 0.0001). Additionally, significant differences were found between groups (P = 0.0165) and between hand used to perform the task (P = 0.0039) while no significant differences were detected between types of task (P = 0.0677). That is, within each task there was a significant difference between

TABLE 3.7

Summary Table of Qualitative Rating Score by Subject Group, Task, and Hand Used To Perform The Task

SUBJECT GROUP	TASK					
	WORDS		FIGURES		TRACING	
	HAND USED TO PERFORM THE TASK					
	Rhand	Lhand	Rhand	Lhand	Rhand	Lhand
RH-N	1.94 (0.22)	2.38 (0.41)	1.94 (0.22)	2.28 (0.19)	1.96 (0.10)	2.26 (0.20)
LH-N	2.00 (0.08)	2.05 (0.15)	1.98 (0.11)	1.94 (0.11)	2.02 (0.07)	2.03 (0.10)
LH-I	2.10 (0.13)	1.98 (0.08)	2.10 (0.09)	2.00 (0.03)	2.05 (0.07)	2.01 (0.04)

*Judges rated subjects as follows:

1 = minimum vertical amplitude
2 = minimum to moderate vertical amplitude
3 = moderate vertical amplitude
4 = moderate to maximum vertical amplitude
5 = maximum vertical amplitude

the hands used to perform the task. However, within each subject group there was no significant task difference. See Table 3.8 for summary of ANOVA.

Writing words

Results of multiple pairwise post hoc comparison t-tests of means and standard deviations by group and hand used to perform the task within the writing task are reported in Figure 3.1. and Table 3.9. Results revealed that when writing words: a) the nondominant, left hand responses of Right-Handed Noninverters (x = 1.48, 0.43) were significantly greater in amplitude than their dominant, right hand responses (x = 0.97, 0.24, P = 0.0002); b) the dominant, left hand responses of Left-Handed Noninverters (x = 1.05, 0.14) were not significantly different from their nondominant, right hand responses (x = 1.00, 0.05, P = 0.2381); and c) the nondominant, right hand responses of Left-Handed Inverters (x = 1.10, 0.13) were significantly greater than their dominant, left hand responses (x = 0.99, 0.08, P = 0.0178).

Drawing figures

Results of subject group performance as determined by the particular hand used to perform the task on the drawing task can be found in Figure 3.2. and Table 3.10. Results revealed that when drawing figures: a) the nondominant, left hand responses of Right-Handed Noninverters (x = 1.28, 0.18) were significantly greater than their dominant, right hand

TABLE 3.8

Summary Table of Repeated Measures Analysis of Variance

Source	df	MS	F value	Pr > F
Group x Task x Hand Used	4	0.1040	9.41	0.0001***
Group	2	0.298	4.66	0.0165
Task	2	0.0726	2.81	0.0677
Hand Used	1	0.5948	9.57	0.0039**
Group x Task	2	0.0726	2.81	0.0677
Group x Hand Used	1	1.0127	43.76	0.0001***
Task x Hand Used	2	0.3822	6.30	0.0048**

*P < .05
**P < .01
***P < .001

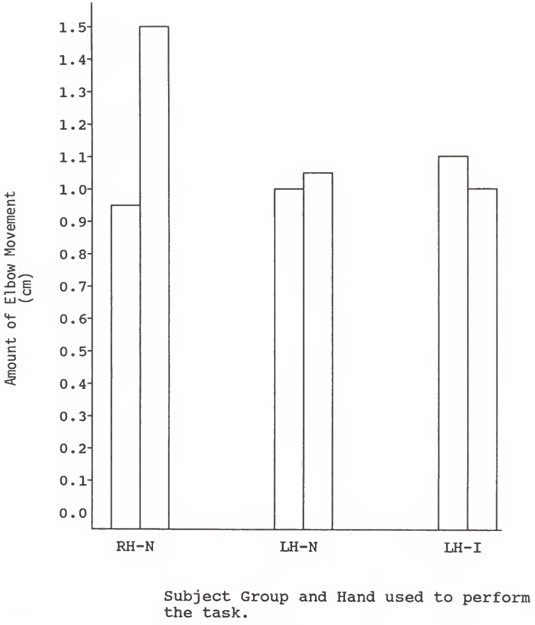


Figure 3.1. Vertical Elbow Amplitude.
Writing Words - Subject Group x Hand Used to Perform the Task Results.

TABLE 3.9

Vertical Elbow Amplitude. Results of Subject Group x Hand Used to Perform the Writing Task.

	Right Hand	Left Hand	PR > /T/
RH-N	0.97	1.48	0.0002***
LH-N	1.00	1.05	0.2381
LH-I	1.10	.99	0.0178*

RH-N = Right-Handed Noninverters
LH-N = Left-Handed Noninverters
LH-I = Left-Handed Inverters

*P < .05
**P < .01
***P < .001

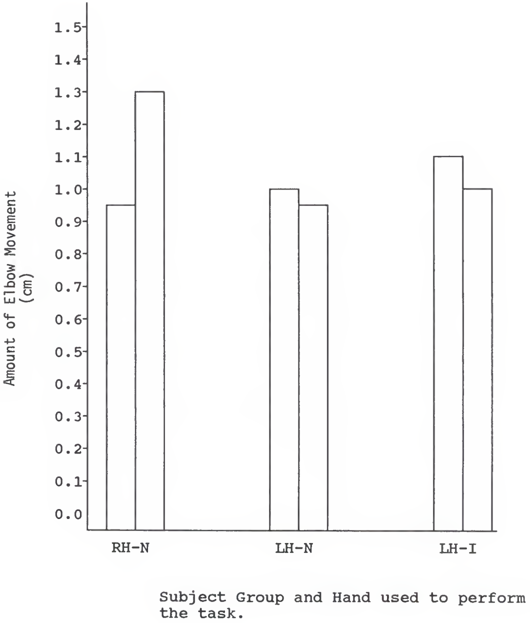


Figure 3.2. Vertical Elbow Amplitude.
Drawing Nonsense Geometric Figures - Subject Group x Hand Used to Perform the Task Results.

TABLE 3.10

Vertical Elbow Amplitude. Results of Subject Group x Hand Used to Perform the Drawing Task.

	Right Hand	Left Hand	PR > /T/
RH-N	0.93	1.28	0.0001***
LH-N	0.98	0.94	0.2619
LH-I	1.08	1.00	0.0093**

RH-N = Right-Handed Noninverters
LH-N = Left-Handed Noninverters
LH-I = Left-Handed Inverters

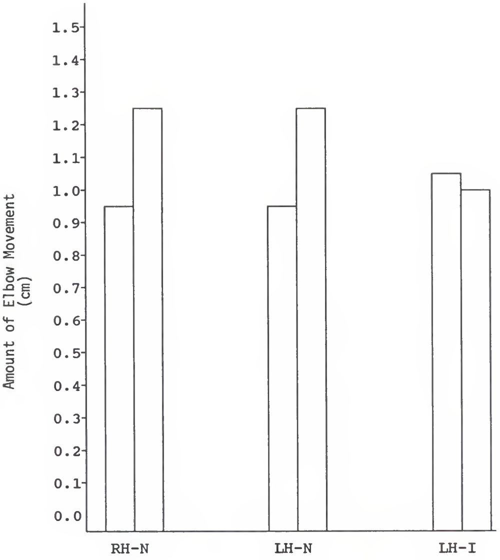
*P < .05
**P < .01
***P < .001

responses (x = 0.93, 0.09, P = 0.0001); b) the dominant, left hand responses (x = 0.94, 0.10) and nondominant, right hand responses (x = 0.98, 0.10) of Left-Handed Noninverters were not different (P = 0.2619); and c) the nondominant, right hand responses of Left-Handed Inverters (x = 1.08, 0.10) were significantly greater than their dominant, left hand responses (x = 1.00, 0.01, P = 0.0093).

Tracing words and figures

Results of subject group performance as determined by the particular hand used to perform the task on the tracing task can be found in Figure 3.3 and Table 3.11. Results of group performances revealed that when tracing words and figures: a) the nondominant, left hand responses of Right-Handed Noninverters (x = 1.26, 0.20) were significantly greater than their dominant, right hand responses (x = 0.96, 0.10, P = 0.0001); b) the dominant, left hand responses of Left-Handed Noninverters (x = 1.26, 0.20) were significantly greater than their nondominant, right hand responses (x = 0.96, 0.10, P = 0.0001); and c) the nondominant right hand responses of Left-Handed Inverters (x = 1.05, 0.06) were greater than their dominant, left hand responses (x = 1.01, 0.02, P = 0.0645).

No significant differences were detected for sex or familial history of handedness.



Subject Group and Hand used to perform the task.

Figure 3.3. Vertical Elbow Amplitude. Tracing Words and Figures - Subject Group x Hand Used to Perform the Task Results.

TABLE 3.11

Vertical Elbow Amplitude. Results of Subject Group x Hand Used to Perform the Tracing Task.

	Right Hand	Left Hand	PR > /T/
RH-N	0.96	1.26	0.0001***
LH-N	0.96	1.26	0.0001***
LH-I	1.05	1.01	0.0645

RH-N = Right-Handed Noninverters
LH-N = Left-Handed Noninverters
LH-I = Left-Handed Inverters

*P < .05
**P < .01
***P < .001

From the statistical and descriptive analysis of data generated from the present study, the following significant findings were perceived to be characteristic of the handwriting movements of Right-Handed Noninverters, Left-Handed Inverters, and Left-Handed Noninverters.

1. Right-Handed Noninverters, evaluated by two naive observers, were perceived to exhibit significantly more elbow movement when writing words, drawing nonsense geometric figures, and tracing words and figures with their nondominant, left hand than when writing words, drawing nonsense geometric figures, and tracing words and figures with their dominant, right hand.

2. Left-Handed Inverters, evaluated by two naive observers, were perceived to exhibit significantly more elbow movement when writing words, drawing nonsense geometric figures, and tracing words and figures with their nondominant, right hand than when writing words and drawing nonsense geometric figures with their dominant, left hand.

3. Left-Handed Noninverters, evaluated by two naive observers, were perceived to exhibit no significant differences in elbow movement when writing words, drawing nonsense geometric figures, and tracing words and figures with either their dominant, left hand or their nondominant, right hand.

4. Right-Handed Noninverters, evaluated by a third naive observer, were found to exhibit significantly more elbow movement when writing words, drawing nonsense geometric figures, and tracing words and figures with their nondominant, left hand than when writing words, drawing nonsense geometric figures, and tracing words and figures with their dominant right hand.

5. Left-Handed Inverters, evaluated by a third naive observer, were perceived to exhibit significantly more elbow movement when writing words and drawing nonsense geometric figures with their nondominant, right hand than when writing words and drawing nonsense geometric figures with their dominant, left hand. Also, there was a trend for these subjects to perform with more elbow movement when tracing words and figures with their nondominant,

right hand than when tracing words and figures with their dominant, left hand.

6. Left-Handed Noninverters, evaluated by a third naive observer, were found to exhibit no significant differences in elbow movement when writing words and drawing nonsense geometric figures with either their dominant, left hand or their nondominant, right hand. However, these subjects did show significantly more elbow movement when tracing words and figures with their dominant, left hand than when tracing words and figures with their nondominant, right hand.

CHAPTER 4

DISCUSSION

It was the purpose of the present study to systematically evaluate three potential influences on the hemispheric specialization for hand movements in normal individuals. The present experiment evaluated the vertical elbow amplitude of thirty-six normal adult's handwriting movements as judged by three persons naive to the research hypotheses.

The following theories were investigated:

1. Language Dominance Theory--According to the language dominance theory it is cognitive specialization that underlies hand asymmetries. Furthermore, based on this hypothesis it was predicted that normal, right-handed and left-handed individuals, representing three distinct groups of subjects according to handedness and handwriting posture, would perform differently on a writing task. Specifically, the handwriting movements of Right-Handed Noninverters and Left-Handed Inverters were expected to be the same. In addition, the handwriting movements of Right-Handed Noninverters and Left-Handed Inverters were both expected to be quite the opposite of the handwriting movements of Left-

Handed Noninverters. That is, based on results of previous investigations of language dominance and handwriting posture (Levy and Reid, 1976; 1978) and previous investigations of the contralateral hemisphere controlling both distal and proximal limb movements and the ipsilateral hemisphere controlling proximal limb movements (Brinkman and Kuypers, 1973), Right-Handed Noninverters and Left-Handed Inverters were expected to use distal (finger/wrist) movements when writing with the right hand and proximal (shoulder) movements when writing with the left hand. In contrast, according to Levy and Reid (1976; 1978) Left-Handed Noninverters were expected to show the opposite pattern of distal movements when writing with the left hand and proximal movements when writing with the right hand. However, Rasmussen and Milner (1975) demonstrate that the majority of left-handers are left hemisphere dominant for language. It should be noted that left handedness was determined solely on the basis of hand preference and there was no mention of these persons' preferred handwriting posture. Therefore, as an alternative to the above predictions, based on their finding, the majority of left-handers were expected to show distal movements with their right hand and proximal movements with their left hand while 15 percent of left-handers were expected to show distal left hand movements and proximal right hand movements and yet

another 15 percent were expected to show no differences between left hand and right hand movements.

It was further hypothesized that since language is not required in order to draw nonsense geometric figures, subjects' motor performances when drawing would be guided by the hemisphere that was dominant for visuospatial functions. In Right-Handed Noninverters and Left-Handed Inverters it was predicted that the specialized visuospatial abilities of their nondominant, right hemisphere would determine the pattern of their preferred hand/nonpreferred hand--distal/proximal movements when drawing. Accordingly, it was postulated that Right-Handed Noninverters would use distal movements when drawing nonsense geometric figures with their left hand and proximal movements when drawing the same figures with their right hand, or show no differences between the drawing movements of their right and left hands. Consistent with Levy and Reid's (1976, 1978) findings, Left-Handed Inverters were also expected to show distal drawing movements with their left hand and proximal drawing movements with their right hand while Left-Handed Noninverters, on the other hand, were expected to use distal movements when drawing figures with their right hand and proximal movements while drawing figures with their left hand as influenced by distal/proximal control from their language dominant, right hemisphere and nondominant left hemisphere. Alternatively, Rasmussen and Milner's (1975)

summary of Wada test results for hemispheric language dominance, the majority, approximately 70%, of all left-handers (with no mention of handwriting posture) were expected to show distal drawing movements with their left hand and and proximal drawing movements with their right hand while 15% were expected to show the opposite pattern, distal drawing movements with their right hand and proximal drawing movements with their left hand. Still, another minority of left-handers were expected to show no differences in left versus right hand movements in the drawing task.

Finally, based on the cognitive hypothesis it was proposed that on the tracing task, a closed loop task that requires sensory feedback (rather than language or visuospatial functions) in order to correctly perform the movements, all three groups of subjects (Right-Handed Noninverters, Left-Handed Noninverters, and Left-Handed Inverters) would show similar hand movement performance pattern. Right-Handed Noninverters, Left-Handed Noninverters, and Left-Handed Inverters were all expected to show no differences between their right hand and left hand movements while tracing words and nonsense geometric figures.

2. Internal Praxis Representation Theory--When writing, one not only requires language knowledge but also needs to know what movements are needed to produce

graphemes. According to the praxis theory these movement formulaes may be lateralized. According to Liepmann, these lateralized movement formulaes may be the major determinant of handedness such that right-handers have movement formulaes in their left hemisphere and left-handers have movement formulaes in their right hemisphere. If these lateralized movement formulaes are the mechanism behind right/left - distal/proximal asymmetries, then right-handed subjects were expected to use distal contralateral movements when writing or drawing with their right hand and ipsilateral shoulder movements when writing or drawing with their left hand. According to the praxis theory, all left-handed subjects were expected to use distal movements while writing and drawing with their left hand and proximal movements while writing and drawing with their right hand as guided by their right hemisphere motor engrams.

Movement formulaes are not required to make closed loop movements. Because closed loop movements are necessary to correctly perform the tracing task, based on the praxis theory it was expected that all subjects, left-handers and right-handers alike would show no differences between their left hand and right hand movements on the tracing task.

3. Motor Skill Superiority Theory--According to the motor skill theory the superiority of distal movements by the preferred hand could be that the preferred hand is simply more skilled at fine coordinated movements with lack

of influence of handwriting posture. If the right/left--distal/proximal asymmetry was related to motor dexterity, when asked to trace words and figures right-handed subjects were expected to perform with distal movements while using their more skilled right (preferred) hand and proximal movements while using their less skilled left (preferred) hand. Conversely, left-handers were expected to show the opposite pattern. While tracing with their more skilled left hand, distal movements should dominate while proximal movements should characterize the tracing performance of their less skilled right hand.

Accordingly, if motor skill superiority determines lateralized distal versus proximal movements in handwriting and drawing, then when writing words and drawing nonsense figures, right-handed subjects were expected to perform with distal movements while using the right hand and proximal movements while using the left hand while left-handers were expected to show the opposite pattern. It was postulated that all left-handed subjects included in the study would use distal movements while writing words and drawing figures with their left hand and proximal movements while writing the same words and drawing the same figures with their right hand.

The results of the present study will be discussed in terms of the hypotheses tested and findings in the research literature. In some cases the hypotheses were statistically

judged correct, whereas in other cases they were not. By discussing the results in the context of past research findings, a neuropsychological test for handedness will be delineated.

Hypotheses Tested

Language Dominance Theory

First, clinical observations indicate that language disturbances occur more frequently in right-handers following lesions of the left hemisphere than following lesions of the right hemisphere. To account for this asymmetry, Broca (1864) suggested a relationship between handedness and speech, wheareas the left hemisphere may be able to mediate language and movement of the right hand. Second, findings in aphasic agraphic patients suggest that the left hemisphere may have a special role in the writing process as well. Lichtheim (1885) and Head (1926) proposed that the reason that disorders of writing and disorders of language often occurred simultaneously was because the acquisition of writing was superimposed on language. Roeltgen (1985) later suggested that writing may be performed by the dominant hand (and nondominant hand) because of knowledge of graphemes.

Second, Mack, Heilman, and Rothi (1987) postulated that in normal right-handers, the left hemisphere influences the

distal right extremity and the proximal left extremity while these persons are engaged in a handwriting activity. The observed greater amplitude of elbow movement for the left hand than the right hand provided support for such a conclusion. As a result of these findings, the language dominance hypothesis was proposed as one possible explanation for the reported findings that handedness influences the use of distal movements when writing with the dominant hand and proximal movements when writing with the nondominant hand.

The first experimental task was designed to assess the influence of language on handwriting movements in three different handedness/hand posture subject groups. These subject groups included Right-Handed Noninverters, Left-Handed Noninverters, and Left-Handed Inverters. Stimuli were presented in the form of cursive written words and subjects were instructed to write them onto a plexiglass board. This writing surface was used in order to permit measurement of vertical elbow movement as a measure of handwriting movement. Finally, when the results were examined as a function of preferred hand and nonpreferred hand performance within subject group, only two of the three groups' comparisons revealed a significant difference--Right-Handed Noninverters and Left-Handed Inverters. No significant differences occurred between the right hand and left hand handwriting movements of Left-Handed Noninverters.

Of great interest was the discrepancy noted in the predictions and results with respect to subject group performance.

Specifically, if language dominance determines handwriting dominance, and if right handers have left hemisphere language, then Right-Handed Noninverters should use distal (finger/wrist) movements when writing with their right hand and proximal (shoulder) movements when writing with their left hand. If Left-Handed Inverters also have language represented in their left hemisphere (Levy and Reid, 1976), then they too should use distal movements when writing with their right hand and proximal movements while writing with their left hand. Furthermore, if 70% of left-handers have language housed in the left hemisphere, 15% have language housed in the right hemisphere, and the remaining 15% have language bilaterally represented as suggested by Rasmussen and Milner (1975), then the majority of Left-Handed Noninverters should use distal movements when writing with the right hand and proximal (shoulder) movements while writing with the left hand. An equally small percentage of Left-Handed Noninverters should use either distal movements when writing with the left hand and proximal movements when writing with the right hand or show no differences in the type of movement used while writing with either hand.

Results of both the Qualitative Rating Scores and the Quantitative Scores support the language dominance theory for right-handers. Right-handed persons used predominantly distal movements when writing words with their right hand and predominantly proximal movements when writing words with the left hand. This finding is interpreted as reflecting an asymmetry in language lateralization associated with handedness that drives distal contralateral movements and proximal ipsilateral movements in right-handers.

However, the scoring results fail to support Levy and Reid's (1976) theory for left hemisphere language dominance in Left-Handed Inverters. Left-Handed Inverters did not perform exactly like the Right-Handed Noninverters, as predicted. Instead, Left-Handed Inverters' right/left - distal/proximal handwriting movments were in the opposite direction of Right-Handed Noninverters. Left-Handed Inverters, used predominantly distal movements while writing words with their left hand and predominantly proximal movements while writing the same words with their right hand. Based on the language hypotheses these results would suggest that language representation for left-handed persons who write in the inverted or "hooked" fashion is located in the right hemisphere and these language representations drive distal and proximal musculatures of the contralateral, left hand and proximal musculatures of the ipsilateral, right hand.

Additionally, results of the writing task fail to support the language dominance theory for noninverted left-handers. The Left-Handed Noninverters, showed no significant difference in their right/left - proximal/distal hand movements on the writing task. The results of this particular task is in agreement with the notion that language may be bilaterally represented in left-handed individuals.

The second experimental task, a drawing task, was designed to allow indirect assessment of the influence of language dominance on distal preferred hand movement and proximal nonpreferred hand movement. If language dominance determines distal/proximal hand movements, and both Right-Handed Noninverters and Left-Handed Inverters have language housed in the left hemisphere (Levy and Reid, 1976), then on a nonlanguage, drawing task, the nonlanguage, right hemisphere should drive hand movements. Right-Handed Noninverters and Left-Handed Inverters were expected to show distal movements with their nonpreferred hands and proximal movements with their preferred hands or no differences between right hand and left hand. Left-Handed Noninverters were expected to show distal preferred (left) hand movements and proximal (right) nonpreferred hand movements while drawing.

Results of both the Qualitative Rating Scores and the Quantitative Scores for the drawing task fail to support the

language dominance theory for right handers and left-handers. Right-Handed Noninverters used predominantly distal movements while drawing with their right hand and predominantly proximal movements while drawing with their left hand. Left-Handed Inverters showed the opposite pattern. They used predominantly distal movements while drawing with their left hand and more proximal movements while drawing with their right hand. Compared to Right-Handed Noninverters' and Left-Handed Inverters' performances on the linguistic task, it appears that even in this nonlinguistic task the dominant language hemisphere drives distal movements while the nondominant hemisphere is responsible for proximal movements. Again, Left-Handed Noninverters showed no significant differences between their right and left hand movements in the drawing task, suggestive of bilateral representation of the mechanism necessary to accomplish the drawing task.

Another task, a tracing task, allowed indirect assessment of the language dominance theory. The tracing task, a closed loop task, also does not require language therefore based on the language hypotheses it was predicted that all subjects would show no differences in their right versus left hand movement performances. Combined results of Qualitative Rating Scores and the Quantitative Scores of subject performance on the tracing task did not lend support for the language dominance theory in Right-Handed

Noninverters nor Left-Handed Inverters. Right-Handed Noninverters used distal movements while performing the tracing task with their right hand and proximal movements while performing the tracing task with their left hand. Left-Handed Inverters, on the other hand, used left hand distal movements and right hand proximal movements while engaged in the tracing task. Instead of performing in the predicted fashion of showing no difference in hand movements it becomes clear from the reported results that a dominant hemisphere mechanism underlies distal movements of the preferred hand and proximal movements of the nonpreferred hand.

Results of the Qualitative Rating Scores did lend support for the language dominance theory in Left-Handed Noninverters but the results of the Quantitative Scores did not. That is, as predicted, Left-Handed Noninverters showed no differences between their left and right hand movements on the tracing task, as judged by the two raters. However, quantitative measurement of Left-Handed Noninverters' left hand and right hand movements revealed that they used predominantly distal movements while tracing with the right hand and predominantly proximal movements while tracing with the left hand. Taken together, these two findings were interpreted as evidence for bilateral representation for hand movements in Left-Handed Noninverters and limitations in the design of the tracing task (to be discussed later).

Internal Praxis Representation Theory

Liepmann (1908) has suggested that it is the lateralized "movement formula" that may underly hand preference. Heilman (1979) postulated that right-handers have representation of movements (space-time engrams) for some skilled acts in their dominant parietal lobe and that these engrams are responsible for providing the motor areas in both hemispheres with the critical information necessary for programming these skilled acts. Perhaps it is these lateralized movement representations for letters that underly the right hand superiority of our right-handed subjects (RH-N) and the left hand superiority of our left-handed subjects (LH-I) for making distal writing movements. If it is the lateralized praxis system rather than language that underlies the right/left proximal-distal asymmetry then one should see these asymmetries with nonverbal material such as nonsense geometric figures. The drawing task of this study was designed to investigate the influence of internal praxis representation, visuokinesthetic motor engrams (Heilman, 1979), on right hand/left hand - proximal/distal handwriting movements. If the left hemisphere motor engrams in right-handers and the motor engrams in the right hemisphere of left-handers are the mechanisms behind these performance asymmetries, then right-handed subjects and all left-handed subjects were expected to perform exactly alike but in opposite directions. That

is, both types of subjects should have used distal movements when drawing with their preferred hand and shoulder movements when asked to draw the same figures with their nonpreferred hand.

Both the results concerning the perceived hand movement scores and the measured hand movement scores provide support for the praxis hypothesis in Right-Handed Noninverters and Left-Handed Inverters. When Right-Handed Noninverters were instructed to draw nonsense geometric figures they used distal contralateral movements (preferred [right] hand) and ipsilateral shoulder movements (nonpreferred [left] hand). This behavior pattern is consistent with the hypothesis that the visuokinesthetic motor engrams of the left hemisphere are responsible for the distal movements of the subjects' right hand and proximal movements of their left hand.

Half of the left-handed subjects, Left-Handed Inverters, performed in the exact opposite direction of the right-handed subjects. They used distal movements when drawing nonsense figures with their preferred (left) hand and proximal (shoulder) movements when drawing the same nonsense figures with their nonpreferred (right) hand. In this particular case, the right hemisphere motor engrams along with the motor system of the right hemisphere is credited with the reported pattern of distal/proximal movements.

The remaining left-handed subjects, the Left-Handed Noninverters, showed no significant differences in their left hand/right hand - proximal/distal movements on the drawing task. This finding is not consistent with the praxis hypotheses but instead suggest that motor engrams are bilaterally represented in left-handed individuals who write in the upright position.

Comparing results of subject performances on the writing task also lend support for the praxis theory in both Right-Handed Noninverters and Left-Handed Inverters. Right-Handed Noninverters used distal movements while writing with their right hand and proximal movements while writing with their left hand. Left-Handed Inverters used distal movements while writing words with their left hand and proximal movements while writing words with their right hand. The results indicate that left hemisphere visuokinestheic motor engrams command the motor system of the ipsilateral hemispheres to control fine (distal) movements of the preferred hand, thus the mechanism of handedness in Right-Handed Noninverters. Likewise, the right hemisphere visuokinesthetic motor engrams command the motor system of the right hemisphere to control distal movements of the left hand, thus the mechanism of handedness in Left-Handed Inverters.

However, results of Qualitative Rating Scores and Quantitative Scores did not support the praxis theory for

Left-Handed Noninverters. Rather than demonstrate distal, preferred hand movements guided by the right hemisphere visuokinestheic motor engrams, Left-Handed Noninverters showed no difference between their left and right hand movements on the writing task. In the context of the present hypothesis, this finding provides evidence for bilateral representation for distal/proximal hand movements in Left-Handed Noninverters.

Further test of the internal praxis representation theory with the aid of a tracing task, a task that should not require praxis representation to drive hand movements, did not lend support for the praxis theory for both Right-Handed Noninverters and Left-Handed Inverters. Right-Handed Noninverters and Left-Handed Inverters used distal movements while tracing with their preferred hand and more proximal movements while tracing with their nonpreferred hand.

Left-Handed Noninverters' hand movements, on the other hand, provided conflicitng results for the tracing task. That is, as perceived by two judges, Left-Handed Noninverters did not show differences between their left hand and right hand movements while tracing words and figures. This finding is in keeping with the prediction of left-handers' performance based on the praxis theory and again we are provided with evidence for bilateral hand movement representations in Left-Handed Noninverters.

In order for the tracing task to have been an on-line task it should have been designed so as to discourage participants from using any kind of representation in order to accomplish the movements but rather rely solely on sensory feedback in order to trace the stimuli from beginning to end. In retrospect, it is surmised that the tracing task of this study did not meet those requirements. Instead, the verbal and nonverbal items chosen for the tracing task could have required that the participants use language and/or movement representations in order to complete the task. A detailed reconstruction of the tracing task can be found in Considerations for Future Research.

Motor Skill Superiority Theory

The motor skill superiority theory may be difficult to dissociate from the praxis theory. However, unlike spontaneous writing or reproductions which are open looped, tracing is closed loop and may not require movement (praxic) representations. If the right/left - proximal/distal asymmetry observed by Mack et al. (1987) was related to motor dexterity, when asked to simply trace words and geometric figures, right-handed individuals would be predicted to perform with distal movements while using the right hand and proximal movements while using the left hand. All left handers, on the other hand, would be expected to show the opposite pattern. While tracing with the left

hand, distal movements should dominate while proximal movements should characterize the tracing performance of the right hand. If, however, internal praxic representations are responsible for the preponderance of distal movements with contralateral preferred hand as opposed to the ipsilateral non-preferred extremity, same asymmetries should not be seen with tracing as those seen with spontaneous writing or drawing or with copying.

Results of the tracing task did support the motor dexterity hypothesis for Right-Handed Noninverters. Right-handers demonstrated distal movements while tracing words and figures with their preferred (right) hand and proximal movements while tracing the same words and figures with their nonpreferred (left) hand. This provides evidence that distal movements require finer, more coordinated movements and right-handers use distal and proximal musculatures of the right extremity rather than the left extremity when tracing because the right hand is more skilled in making fine, coordinated movements.

Also, results of Left-Handed Inverters' tracing performance lent support for the motor skill superiority theory. The left-handed subjects who assumed the inverted writing position, Left-Handed Inverters, used predominantly distal movements while tracing with their left hand and predominantly proximal movements while tracing with their right hand. Unlike right-handed individuals these left-

handed inverted writers use distal and proximal musculatures of the left extremity rather than their right extremity because the left hand is more skilled in making fine, coordinated movements.

Left-Handed Noninverters, on the other hand, used distal movements while tracing with their right hand and proximal movements while tracing with their left hand.

Results of the Qualitative Rating Scores and the Quantitative Scores for both the writing task and the drawing task provide further support for the motor superiority theory for Right-Handed Noninverters and Left-Handed Inverters. Both Right-Handed Noninverters and Left-Handed Inverters used more distal movements when writing words and drawing figures with their preferred hand as compared to more proximal movements when writing words and drawing figures with their nonpreferred hand. Taken together, these results provide evidence that the skilled, preferred hand drives distal and proximal movements while the less skilled, nonpreferred hand drives proximal movements.

The results of Left-Handed Noninverters' performance on the writing and drawing tasks provide no evidence for a motor skill superiority theory. Left-Handed Noninverters showed no differences in their preferred hand versus nonpreferred hand movements. Although the findings do not support the proposed theory it provides further support for

bilateral representation of hand movements in Left-Handed Noninverters.

General Discussion

In the foregoing tasks, language dominance, internal praxis representation and motor skill superiority theories and handedness were investigated in normal subjects. Specifically, the question was addressed as to whether language dominance, internal praxis representation, or motor skill superiority determine handedness and as a result how each might influence the type of movement one makes while writing. Additionally, handedness and handwriting posture were two variables included in the investigation.

When considering the findings of the study, it is important to discuss the results in terms of handedness/handwriting posture group (Right-Handed Noninverters, Left-Handed Inverters, and Left-Handed Noninverters) performances and its relationship to the proposed theories. First, Right-Handed Noninverters consistently used distal right hand movements and proximal left hand movements while performing the three tasks (writing, drawing, and tracing). These tasks were designed to distinguish between the possible influence of lateralized language, praxis and motor functions. The question arises as to whether left hemisphere lateralized language function,

left hemisphere lateralized praxis representation, or left hemisphere motor system superiority affect hand movement. The data of all three tasks indicate that Right-Handed Noninverters do indeed use distal preferred hand movements and proximal nonpreferred hand movements due to influence from specific lateralized functions of their left hemisphere. The best fitting model to explain the hand movements observed in the right-handed individuals included in this study is the motor skill superiority model or dexterity model. As predicted (see Table 1.1) Right-Handed Noninverters used distal movements with their preferred hand and proximal movements with their nonpreferred hand regardless of the type of task that they were given. However, it should be noted that if the tracing task was not truely closed loop as intended, then the internal praxis representation serves as the best model to explain the Right-Handed Noninverters' hand movements.

Conversely, Left-Handed Inverters consistently used distal left hand movements and proximal right hand movements while performing the writing, drawing, and tracing task. On the basis of those findings, it is again concluded that the dexterity model fits as the best explanation for the observed hand movements of Left-Handed Inverters. However, it should again be noted that, if the tracing task was not representative of a closed loop task as intended then the

internal praxis representation serves as the best model to explain the Left-Handed Inverters hand movements.

As previously indicated, the findings of Left-Handed Noninverters' performances are difficult to interpret based solely on the proposed variables (subject handedness/ handwriting posture group, hypothesis, and type of task). Let us consider them separately in terms of the reported qualitative hand movement scores and the quantitative hand movement scores. Left-Handed Noninverters were consistently perceived as exhibiting no differences in their left hand versus right hand movements while performing the writing, drawing and tracing tasks. It appears then that these individuals could have bilateral language, praxis, and superior motor skill representation for hand movements. It should be mentioned, however, that their measured hand movement performance is not consistent with the above findings. Like their perceived movement scores, measured movement scores indicated no differences between the amount of movement of their left hand and right hand on the writing and drawing tasks. However, differences between Left-Handed Noninverters' right hand and left hand movements on the tracing task revealed a trend for them to use distal right hand movements and proximal left hand movements. Since the differences detected between the Left-Handed Noninverters' right hand and left hand tracing performance did not reach a level of significance and since this qualitative-

quantitative discrepancy was noted only on the tracing task, it appears that the findings can not be explained in terms of influence from brain functions but rather in terms of limitations of the study (see Considerations for Future Research).

Considerations for Future Research

Methodological Considerations

As discussed the motor skill theory appeared to be supported by the tracing task. However, the tracing task may have not measured what it was intended to measure. The tracing task was included in the study in order to allow direct assessment of the influence of the motor system on hand movements. Neither language nor internal praxis representation but rather sensory feedback and motor control are required in accomplishing such a task. Therefore, it was assumed that the tracing task was quite different (closed-loop) from the other tasks (open-loop) and would produce different results. It appears that the assumptions were not met and performance may reflect resulting open loop movements. Half of the stimuli items in the tracing task were the same familiar words that were used in the writing task. Now in order to trace the outlines of these words the subject not only had the assistance of sensory feedback but also could rely on the familiar linguistic features of these

words. With that in mind, the tracing task became an open loop movement task and the hand movements could have been directed from the subject's language hemisphere.

In order for the task to be closed loop, the task needs to be redesigned. First of all, the stimulus items should consist of unfamiliar, nonsense figures. That is, stimulus items in the tracing task should not be included in the language and praxis tasks. In addition because seeing the figure before it is traced may lead to the formation of a representation for the figure it is suggested that the task be designed so that the subject receives only part of the target figure over a period of time. A moving dot on a television screen (or computer monitor) and a stylus are the suggested research writing tools to be used. Specifically, the subject should be seated in front of the television screen and instructed to place the stylus on the dot (at the starting point of the figure) and follow the continuous random movements of a dot until it (the dot) stops (at the end of the figure). This procedure should result in the production of a nonsense figure made by closed loop movements. Additionally (and probably most importantly) the outlined word or figure that is traced should be videotaped for the measurement and analysis of movement in three-dimensional space.

The procedures for this proposed study were developed for the complex hand and arm movements of American Sign

Language (Poisner, Klima, Bellugi and Livingston, 1983; Loomis, Poizner, Bellugi, Blakemore and Hollerbach, 1983; Poizner, 1981) and later adopted for the analysis of apraxic production of pantomime in three dimensional space (Poizner, Rothi, Verfaillie, Mack and Heilman, 1987). The subjects' tracing movements can be digitized with the aid of special opto-electronic cameras (OP-EYE System) that can digitize the positions of infrared-emitting diodes that can be taped to the major joints of the participant's arm. Two opto-electronic cameras can be used to digitize movements from neighboring viewpoints. The three dimensional coordinates of each joint can be calculated from the two cameras by triangulation, with knowledge of relative camera position and orientation. The three dimensional movement coordinates can then be reconstructed through a computer graphics system in order to allow visualization of the movement trajectories. This three-dimensional output will allow separate analysis of various temporal and spatial characteristics of any segment of the movement trajectory.

Another methodological consideration addresses the issue of statistical analysis. In order to assess the qualitative rating scores as free from error, correlation coefficents were computed and reliability testing was attempted. The correlations between qualitative rating scores (for all subjects, on all tasks) of Judge #1 and Judge #2 were not consistently high (.90) suggesting a low

degree of reliability for the qualitative measurements. As a result of low correlations reliability testing could not be done. Therefore, any differences detected in the subjects' handwriting movements were either attributed to subject preferred hand versus nonpreferred hand differences or Judge #1 versus Judge #2 rating differences. Future research should increase rater training from one week to three weeks or more with inter-rater reliability assessments in one-week increments. Failure to achieve a high degree of reliability for the rating scores of both judges after three weeks of training would warrant the need for two new judges. Another alternative to solving the inter-rater reliability problem would be to increase the number of raters. Instead of the two raters used in the present study, three raters should be employed to view (and score) the videotapes. Correlation coefficient computations after three weeks of training would allow one to assess inter-rater reliability. In the event that one of the three raters scores subject handwriting performances significantly different from the other two raters, that rater would be dropped from the study and videotape scoring would continue with the two "highly reliable" raters.

Theoretical Considerations

In addition to redesigning the third task of the experiment for use with normal controls, further

consideration should be given to conducting the entire research experiment with braindamaged individuals. Specifically, it is the investigator's intent to test the model of internal praxis representation and hand movements in ideomotor apraxic patients. Left hemisphere damaged apraxic and nonapraxic patients and right hemisphere damaged patients along with their normal controls will be participants in the proposed study. If internal praxic representations are responsible for the preponderance of distal movements with contralateral preferred hand as opposed to the ipsilateral non-preferred extremity, when performing the drawing and writing tasks it is predicted that apraxic patients will use less distal movements with their nonhemiplegic left hand than will nonapraxic controls.

In like manner, the same research paradigm will be considered for use with right-handed and left-handed nonapraxic patients with commissurotomy and their age-matched left-handed and right-handed normal controls in order to test the language dominance model for hand movements. It is hypothesized that right-handers and left-handers will perform the writing task with distal preferred hand movements and proximal nonpreferred hand movements, the drawing task with distal nonpreferred hand movements and proximal preferred hand movements and the tracing tasks with no differences between preferred hand and nonpreferred hand

movements if indeed language representation is the mechanism behind handedness (hand movements).

In the present investigation, three groups of handedness/handwriting posture subjects were studied: Right-Handed Noninverters, Left-Handed Noninverters, and Left-Handed Inverters. Future studies might continue to explore distinctions between preferred hand versus nonpreferred hand writing movements with four groups of handedness/handwriting posture subjects: Right-Handed Noninverters, Right-Handed Inverters, Left-Handed Noninverters, and Left-Handed Inverters.

Finally, although differences were found between the two groups of left-handers included in this study, other questions about handwriting posture remain unresolved and await future research. Is there a relationship between birth stress factors that might signify subtle neurological pathology and writing hand posture? Future research could also compare a larger pool of Left-Handed Noninverters and Left-Handed Inverters on the basis of sex, age, and education to determine whether or not the reported results were representative of left-handers in general or influenced by the select group of middle-class, educated left-handed subjects included in this study.

Implications

This study tells me that what the nondominant hemisphere has the potential to contribute might be signaled

by the handedness/writing posture of the patient. For the Left-Handed Noninverter, as evidenced by the results of this study, both hemispheres of the brain have equal potential to contribute to the writing process. Therefore, in the treatment of agraphia it becomes important to assess the agraphic patient's premorbid handedness and handwriting posture in order to effectively treat the writing disorder.

APPENDIX A
SUBJECT INFORMATION

HANDEDNESS	SEX	AGE	EDUCATION	FAMILIAL HANDEDNESS
RH-N	M	38	College 2	Right
	M	35	College 3	Right
	M	34	College 6	Right
	M	33	College 6	Right
	M	32	College 2	Right
	M	25	College 7	Right
	F	31	College 8	Right
	F	30	College 3	L - Father
	F	28	College 6	Right
	F	23	College 4	Right
	F	22	College 5	Right
	F	18	College 1	Right
LH-N	M	29	College 9	Right
	M	29	College 2	Right
	M	25	College 8	Right
	M	24	College 6	Right
	M	24	College 6	Right
	M	19	College 2	Right
	F	40	College 1	Right
	F	32	College 4	Right
	F	27	College 6	Right
	F	24	College 4	L - Father
	F	19	College 2	L - Mother
	F	18	College 1	Right
LH-I	M	50	College 2	Right
	M	40	College 9	Right
	M	36	College 9	Ambi - Mother
	M	32	College 4	Right
	M	29	College 4	Right
	M	27	College 7	Right
	F	45	College 5	Right
	F	33	College 4	Right
	F	25	College 2	Right
	F	24	College 3	Right
	F	20	College 3	Right
	F	18	College 1	L - Mother

APPENDIX B

WATERLOO HANDEDNESS QUESTIONNAIRE II

Instructions: Answer each of the following questions as best you can. If you always use one hand to perform the described activity, circle **Ra** or **La** (for **right always** or **left always**). If you **usually** use one hand circle **Ru** or **Lu** (for **usually right** or **usually left**), as appropriate. If you use **both hands equally often**, circle **Eq**.

Do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, then mark the appropriate answer. If necessary, stop and pantomime the activity.

1.	Which hand do you use for writing?	La	Lu	Eq	Ru	Ra
2.	With which hand would you turn on a water tap?	La	Lu	Eq	Ru	Ra
3.	With which hand would you throw a dart?	La	Lu	Eq	Ru	Ra
4.	In which hand would you hold a heavy object?	La	Lu	Eq	Ru	Ra
5.	With which hand would you unscrew a tight jar lid?	La	Lu	Eq	Ru	Ra
6.	In which hand do you hold your toothbrush?	La	Lu	Eq	Ru	Ra
7.	With which hand would you pick up a penny off a desk?	La	Lu	Eq	Ru	Ra
8.	On which shoulder do you rest a baseball bat when batting?	La	Lu	Eq	Ru	Ra
9.	With which hand do you throw a baseball?	La	Lu	Eq	Ru	Ra
10.	With which hand would you pet a cat or a dog?	La	Lu	Eq	Ru	Ra
11.	With which hand would you draw a picture?	La	Lu	Eq	Ru	Ra
12.	In which hand would you carry a heavy suitcase?	La	Lu	Eq	Ru	Ra

13.	In which hand would you hold a match to strike it?	La	Lu	Eq	Ru	Ra
14.	In which hand would you hold a hammer to drive a nail?	La	Lu	Eq	Ru	Ra
15.	With which hand would you pick up a glass of water?	La	Lu	Eq	Ru	Ra
16.	Which hand would you use to dial a number on a push button phone?	La	Lu	Eq	Ru	Ra
17.	Over which shoulder would you swing an axe?	La	Lu	Eq	Ru	Ra
18.	With which hand would you point to a distant object?	La	Lu	Eq	Ru	Ra
19.	Which hand would yo use to catch a ball if you were barehanded?	La	Lu	Eq	Ru	Ra
20.	In which hand do you hold scissors to cut paper?	La	Lu	Eq	Ru	Ra
21.	In which hand do you hold a tennis racket?	La	Lu	Eq	Ru	Ra
22.	With which hand would you pick up a screw?	La	Lu	Eq	Ru	Ra
23.	With which hand would you hit someone?	La	Lu	Eq	Ru	Ra
24.	In which hand would you hold a fly-swatter when killing flies?	La	Lu	Eq	Ru	Ra
25.	With which hand do you use a pair of tweezers?	La	Lu	Eq	Ru	Ra
26.	With which hand would you throw a spear?	La	Lu	Eq	Ru	Ra
27.	With which hand would you tighten a screw by hand?	La	Lu	Eq	Ru	Ra
28.	Which hand do you put down on the floor first when doing a cartwheel?	La	Lu	Eq	Ru	Ra

29. With which hand would you hold a cloth when dusting the furniture?	La	Lu	Eq	Ru	Ra
30. With which hand would you hold the razor when shaving?	La	Lu	Eq	Ru	Ra
31. With which hand do you flip a coin?	La	Lu	Eq	Ru	Ra
32. Which shoulder would you use to push open a pair of swinging doors (cafe style) when your arms were full?	La	Lu	Eq	Ru	Ra
33. With which hand do you wind a stopwatch?	La	Lu	Eq	Ru	Ra
34. With which hand would you pick up a paperclip off a desk?	La	Lu	Eq	Ru	Ra
35. With which hand do you use a eraser on the end of a pencil?	La	Lu	Eq	Ru	Ra
36. With which hand would you insert a pin into material?	La	Lu	Eq	Ru	Ra
37. With which hand would you pick up a piece of paper off a desk?	La	Lu	Eq	Ru	Ra
38. With which hand would you shoot a marble?	La	Lu	Eq	Ru	Ra
39. With which hand would you wash your face with a cloth?	La	Lu	Eq	Ru	Ra
40. With which hand would you hold a needle when sewing?	La	Lu	Eq	Ru	Ra
41. With which hand would you pick up the receiver of a telephone?	La	Lu	Eq	Ru	Ra
42. Which hand would you use to wave goodbye?	La	Lu	Eq	Ru	Ra
43. Which hand would you use to snap your fingers?	La	Lu	Eq	Ru	Ra
44. Which hand would yo use to pick up a marble?	La	Lu	Eq	Ru	Ra

45. Which hand would you use in baseball?	La	Lu	Eq	Ru	Ra
46. In which hand would you hold the paperclip when clipping papers together?	La	Lu	Eq	Ru	Ra
47. Which hand would you use to screw in a light bulb?	La	Lu	Eq	Ru	Ra
48. With which hand do you hold a comb when combing your hair?	La	Lu	Eq	Ru	Ra
49. With which hand would you pick up a book?	La	Lu	Eq	Ru	Ra
50. With which hand would you pick up a pin?	La	Lu	Eq	Ru	Ra
51. With which hand would you extract a small object from a tight space?	La	Lu	Eq	Ru	Ra
52. With which hand would you shoot a basketball?	La	Lu	Eq	Ru	Ra
53. With which hand would you pick up a heavy suitcase?	La	Lu	Eq	Ru	Ra
54. Which hand would you use to erase a blackboard?	La	Lu	Eq	Ru	Ra
55. Which hand is the most adept at picking up small objects?	La	Lu	Eq	Ru	Ra
56. Do you consider yourself a left-handed or right-handed baseball batter?	La	Lu	Eq	Ru	Ra
57. If both hands were empty which hand would you use to break your fall if you slipped on ice?	La	Lu	Eq	Ru	Ra
58. Which hand do you use to manipulate implements such as tools?	La	Lu	Eq	Ru	Ra
59. Which hand do you consider to be the strongest?	La	Lu	Eq	Ru	Ra
60. In which hand would you hold a knife to cut bread?	La	Lu	Eq	Ru	Ra

APPENDIX C

COUNTERBALANCE DESIGN OF SUBJECTS AND CONTITIONS

SUBJECTS	SEX	CONDITIONS		
RH-N	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing
LH-N	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing
LH-I	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	M	Word	Drawing	Tracing
	M	Drawing	Tracing	Word
	M	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing
	F	Word	Drawing	Tracing
	F	Drawing	Tracing	Word
	F	Tracing	Word	Drawing

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BIOGRAPHICAL SKETCH

Linda Mack was born on January 23, 1960, in Charleston, South Carolina, and grew up on a neighboring sea island, James Island, South Carolina. She graduated from Fort Johnson High School (James Island, South Carolina) in 1978 and attended South Carolina State College in Orangeburg, South Carolina, from 1978 through 1982. She graduated magna cum laude from South Carolina State College in 1982 with a bachelor's degree in speech pathology and audiology.

In the summer of 1982 she began graduate school in speech pathology and phonetic science at the University of Florida under a two year University of Florida Graduate School Minority Fellowship. During her studies she became interested in scientific investigation of her native creole language, Gullah, and in 1984 completed her master's thesis, "A Comparative Analysis of Linguistic Stress Patterns in Gullah and English Speakers."

After a year traineeship with the Veterans Administration Medical Center in Gainesville, Florida, her research interests expanded to the area of neurogenic communication disorders. In 1985 she was awarded a McKnight

Doctoral Fellowship and began her doctoral studies at the University of Florida and completed her work in January of 1989.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Leslie J. Gonzalez Rothi

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ira S. Fischler

Ira S. Fischler
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the Department of Speech in the College of Liberal Arts and Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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